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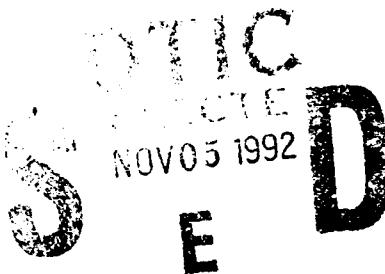


ARMSTRONG

LABORATORY

## AUTOMATIC INFORMATION PROCESSING AND HIGH PERFORMANCE SKILLS: TRAINING, TRANSFER, RETENTION, AND WORKLOAD

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## PREFACE

The work documented in this report was conducted under Air Force Armstrong Laboratories (AL) Contract No. F33615-88-C-0015 with the University of Dayton Research Institute. This work supports an integrated research program within the Logistics Research Division of AL which is developing advanced part-task training techniques based on information processing theory. Dr. Beverley A. Gable served as the AL/HRGA, Wright-Patterson Air Force Base, contract monitor.

## I. INTRODUCTION

### Automatic/Controlled Processing and High Performance Skills

Air Force Command and Control (C<sup>2</sup>) system operators can be required to rapidly process large volumes of information associated with multiple concurrent functions performed within such systems. Consequently, efficient use of C<sup>2</sup> systems requires highly skilled operators who can perform under high workload or timesharing conditions. The high-performance skills demanded of operators typically require extensive training to develop and are characterized by qualitative differences in performance between the novice and expert (Schneider, 1985).

The speed, accuracy, and timesharing capabilities that characterize expert performance and can develop with extensive training have led several investigators (e.g., Logan, 1985; Schneider, Dumais, and Shiffrin, 1984; Shiffrin and Schneider, 1977) to propose an automatic/controlled theory of human information processing. Within the automatic/controlled processing theory framework, automatic processing represents a rapid, accurate, parallel, and effortless form of processing that is not limited by the capacity or resource restrictions which typically characterize operator performance. Controlled processing, on the other hand, represents a relatively slow, effortful, and sequential process that reflects resource/capacity limits. Automatic processing develops with extensive training under consistently mapped (CM) conditions for which there is a consistent relationship between task components (e.g., a stimulus and the required response). Controlled processing is associated with variably mapped (VM) conditions for which task component relationships vary from situation to situation.

Automatic/controlled processing theory suggests that automatic processes can constitute important components of skilled operator performance. In this view, certain elements of

skill are associated with the automatization of CM task components, which can contribute to the overall speed and efficiency of expert performance. Because only consistent subcomponents of complex skills can be automatized, most such skills are thought to represent the product of both controlled and automatic processing (Logan, 1985; Schneider et al., 1984; Shiffrin and Dumais, 1981).

The speed and accuracy (e.g., Eggemeier, Granitz, Rogus, and Geiselman, 1990; Eggemeier, Bower, Granitz, Rogus, Mitchell, and Vukelic, 1991; Fisk, Hodge, Lee, and Rogers, 1990; Fisk, Rogers, Lee, Hodge, and Whaley, 1991) that characterize automatic processing indicate that such processes represent potentially important determinants of Air Force C<sup>2</sup> operator performance. In addition to speed and accuracy, two important potential benefits of automatic processing within C<sup>2</sup> systems are reduced workload and improved operator timesharing efficiency. Such improvements can be particularly important because of the high workload associated with operator performance in some C<sup>2</sup> systems. If the processing resource/capacity expenditure associated with a CM task component is reduced through automatic processing, the resources no longer required for CM processing could be applied to other tasks or components, thereby improving timesharing efficiency. Such increases in timesharing efficiency have been demonstrated in several instances for which automatized tasks have been efficiently performed with concurrent controlled processing tasks (e.g., Fisk and Lloyd, 1988; Fisk and Schneider, 1983; Schneider and Fisk, 1982, 1984; Strayer and Kramer, 1990; Venturino, 1991).

#### Automatic/Controlled Processing Theory and Operator Training

The distinction between CM and VM task components has important implications for the design of training programs intended to support the acquisition of automatic processing. Because only CM task components can be automatized, training

programs should be designed to afford numerous repetitions of such components. Therefore, part-task training of CM components is one potentially viable means of providing that training. Such an approach requires that CM components of operator tasks be identified through task analytic procedures and incorporated into part-task trainers to provide the required practice. Task components that are automatized through this training would be subsequently integrated into the total task through whole-task training procedures.

Application of the automatic-processing-based approach to C<sup>2</sup> operator training requires extensions of the current automatic processing data base in several areas. Four important areas include: (a) specification of the conditions that permit automatic process development with the types of information processed by C<sup>2</sup> systems operators, (b) investigation of the transfer associated with automatic processes under conditions encountered within C<sup>2</sup> systems, (c) specification of the retention functions associated with automatic processing of the information types processed by C<sup>2</sup> operators, and (d) investigation of possible reductions in workload and levels of concurrent task performance efficiency associated with automatizing the type of CM task components found in C<sup>2</sup> systems.

Specification of conditions that permit the development of automaticity with major information classes processed by C<sup>2</sup> operators is required to determine the viability of an automatic processing approach to operator training. Some C<sup>2</sup> operators, for example, must process complex alphanumeric rules that represent combinations of acronyms which, in turn, stand for particular system parameters and associated numerical values. These operators must search a display and distinguish alphanumeric sequences that represent parameters within specified numerical tolerances from those that do not. Likewise, some C<sup>2</sup> systems require extensive search for and processing of spatial patterns that represent critical elements of information, such as aircraft

movement and position, which must be detected and recognized against a background of non-critical elements (Eggemeier, Fisk, Robbins, Lawless, and Spaeth, 1988).

Although there has been considerable research on automatic processing in search paradigms that require a distinction between target and distractor items, relatively little work has addressed automatization of the type of complex alphanumeric rules and spatial pattern information processed by operators of C<sup>2</sup> systems. Therefore, it is important to evaluate the effects of extensive training on such complex alphanumeric rules and spatial patterns in order to: (a) investigate if they can develop characteristics of automatic processing, and (b) specify the conditions of training and the types of search for these materials that might affect the development of such processing. The development of automatic processing, for example, usually requires extensive training. Any training techniques (e.g., part-task training) that could facilitate automatic processing development with the types of materials noted above could therefore be of substantial potential benefit to C<sup>2</sup> operator training applications. Also, visual/memory search represents a major component of many C<sup>2</sup> operator functions. Work is required to extend previous research (e.g., Eggemeier et al., 1990, 1991) with spatial pattern information within memory search paradigms to these critical search functions as well.

Data concerning the transfer of automatic subcomponents of operator tasks represent an additional important area for effective design of C<sup>2</sup> operator training programs. Such data are needed, for instance, to determine if operator training with subsets of materials can serve as the basis for subsequent acquisition of similar materials in the type of complex rule-based tasks described above. With spatial pattern information, data are required to evaluate the effect of certain manipulations (e.g., pattern rotation) that can be found in C<sup>2</sup> systems on

operator capability to process previously trained patterns within visual/memory search tasks.

Another significant transfer issue concerns possible task recombinations in which originally trained targets/distractors are incorporated into a new task. Such a task could require that targets/distractors serve either the same or different roles. It is important to determine the levels of operator performance associated with different task recombinations. Previous research with semantic-based, symbolic, and alphanumeric materials in paradigms with a visual search component (e.g., Dumais, 1979; Fisk et al., 1990; 1991; Shiffrin and Schneider, 1977) suggests that negative transfer will result when previous targets are incorporated into a task as distractors, or previous distractors are included in a task as targets. However, it is necessary to investigate extensions of previous transfer work to conditions representative of other subcomponents (e.g., spatial pattern memory search) of C<sup>2</sup> operator tasks.

A third major area relevant to the application of automatic processing to C<sup>2</sup> operator training is the retention of automatic processes. Specification of retention functions for automatic processing is required to effectively design training programs that will maintain skills over periods of disuse. For instance, an air weapons controller might experience a period when certain air intercept missions are not flown; thus, skills associated with such missions are not used. However, when such missions are resumed, controller skills must be at acceptable levels. Information concerning the retention functions associated with skills is essential to determine if refresher training would be required during the period of disuse. Previous research in this program has investigated the retention of automatic processing with semantic and spatial pattern materials (Eggemeier, 1991; Fisk et al., 1990; 1991). Once again, this previous work must be extended to other materials (e.g., alphanumeric rules) that represent analogs of information associated with C<sup>2</sup> operator

tasks, and to search functions (e.g., visual/memory search) with materials representative of those found in C<sup>2</sup> systems.

Finally, a fourth important area that has possible applications to C<sup>2</sup> operator training is the workload reduction typically assumed to accompany the development of automatic processing. As described previously, C<sup>2</sup> systems operators must perform within a high workload environment that can involve concurrent processing demands. Therefore, two major advantages of the automatic processing of task subcomponents would be: reduction in the workload associated with their performance, and the potential for improved timesharing efficiency that would result from such reductions. Several investigators cited above (e.g., Fisk and Lloyd, 1988; Fisk and Schneider, 1983; Schneider and Fisk, 1982, 1984; Strayer and Kramer, 1990; Venturino, 1991) have reported high levels of timesharing efficiency between concurrent and automatic and controlled processing tasks. Other investigators (e.g., Vidulich and Pandit, 1986, 1987; Vidulich and Wickens, 1986) have applied subjective assessment techniques to evaluate the workload associated with performance of automatic and controlled processing versions of a semantic memory search. Vidulich and Pandit (1986), for example, reported that CM memory set size increases led to lower increments in subjective workload than comparable VM increases.

Thus, the present literature supports the position that reduced workload can be associated with automatic processing. However, applications to C<sup>2</sup> operator performance will once again require extension of previous work. Important areas for such extension parallel those noted above, and include analyses of the workload associated with principal classes of information (e.g., spatial pattern, rule-based alphanumeric) processed by C<sup>2</sup> operators within the visual/memory search paradigms that are similar to major subcomponents of operator functions.

### Objectives of the Present Research Program

The present research program investigated the acquisition, transfer, retention, and workload associated with automatic processing in laboratory tasks that represented the information-processing requirements imposed by selected C<sup>2</sup> system task components. This report documents a series of experiments conducted to examine issues concerned with each of these topic areas in laboratory analogs of C<sup>2</sup> task components.

Section II of this report describes a series of four experiments conducted to examine the acquisition of automatic processing in memory search and visual/memory search tasks that involved the processing of information similar to that required of C<sup>2</sup> system operators. Subjective rating assessments of the workload associated with automatic and controlled processing versions of spatial pattern and rule-based alphanumeric visual/memory search tasks were also performed in two of these experiments. Section III presents four experiments that investigated issues pertaining to the transfer of automatic processing in analogs of C<sup>2</sup> tasks, and Section IV describes three experiments that examined the retention of automatic processing of spatial pattern and rule-based alphanumeric information. Section V presents an experiment that investigated the workload associated with performance of a visual/memory search task under automatic and controlled processing conditions through application of secondary task workload assessment methodology. Finally, Section VI provides a general summary and conclusions.

## II. ACQUISITION OF AUTOMATIC PROCESSES IN TASKS REQUIRING THE PROCESSING OF SPATIAL PATTERN INFORMATION AND ALPHANUMERIC RULE-BASED INFORMATION

As indicated above, Air Force C<sup>2</sup> systems (e.g., event detection, air weapons control) require the operator to process a variety of complex spatial and alphanumeric information under high workload conditions (Eggemeier et al., 1988). The information associated with such systems can differ in type and complexity from the relatively simple alphanumeric materials (e.g., individual numerals or letters of the alphabet) employed in many earlier laboratory studies of automatic processing (see Schneider et al., 1984 for a review). Therefore, information from these earlier experiments may not be directly applicable to operator functions that require the processing of spatial and complex alphanumeric materials.

The purpose of the experiments described in this section was to investigate automatic processing development in memory and visual/memory search tasks that required processing information analogous to that associated with the noted Air Force C<sup>2</sup> systems.

### Complex Alphanumeric Information

The first two experiments investigated automatic processing development in memory search and visual/memory search tasks that required the processing of rule-based alphanumeric information. As outlined previously, certain Air Force C<sup>2</sup> systems require the operator to process complex alphanumeric information represented by the conjunction of letter sequences that represent particular system parameters and numerical values that stipulate the status of those parameters. An operator can be required to search a display that contains a number of parameter designators/numerical values, and rapidly determine if the values associated with each parameter fall within specified boundaries. This represents a rule-based search task in which the rule is defined by the conjunction of a system designator and a range of numerical

values, and the search set consists of the combination of a system designator and a numerical value that represents either an exemplar or a non-exemplar of the rule.

Previous research in this program (Eggemeier et al., 1990) has shown that letter sequences similar to those used as system designators can be automatized. Also, there have been a number of recent reports (e.g., Fisk and Lloyd, 1988; Fisk, Oransky, and Skedsvold, 1988; Kramer, Strayer, and Buckley, 1990) about the development of rule-based automatic processing. Eggemeier et al. (1991) have also reported evidence of automatic processing in a rule-based memory search task that employed CM and hybrid VM/CM conditions. Because of the importance of rule-based information within C<sup>2</sup> systems, it was considered important to extend the original Eggemeier et al. (1991) work to include a pure VM condition, and to examine the capability of subjects to automatize the processing of rule-based information within a visual/memory search paradigm that paralleled the search demands imposed by some C<sup>2</sup> systems.

#### Spatial Pattern Information

Experiments 3 and 4 in this series addressed automatic processing of static spatial pattern information within visual/memory search paradigms. As discussed previously, some Air Force C<sup>2</sup> systems place a very heavy emphasis on the capability to search for critical target patterns that portray the presence and movement of certain items (e.g., aircraft) on a system display against a background of distractor patterns. Although spatial pattern information is essential to operator performance within such systems, there has been relatively little research on the automatic processing of such information.

To date, research with spatial pattern information has produced evidence that supports the capability to automatize the processing of such information (e.g., Eberts and Schneider, 1986;

Eggemeier et al., 1990; 1991; Lawless and Eggemeier, 1990; Venturino, 1991). However, much of the work has been conducted within memory search paradigms. Several studies that incorporated visual search components (e.g., Eberts and Schneider, 1986; Lawless and Eggemeier, 1990) produced evidence of only weak automatic processing. Consequently, it was considered important to further investigate the conditions that would permit the development of automatic processing of spatial pattern information within a visual/memory search paradigm.

#### Overview of Present Studies

The following series of four experiments was performed to investigate levels of performance that could be achieved with extended training in tasks requiring the processing of spatial pattern information and complex alphanumeric information. Experiment 1 examined the effects of training on a memory search task that required the processing of rule-based alphanumeric information under three mapping conditions (CM, hybrid VM/CM, and VM). Experiment 2 extended the work in the first experiment and examined the processing of rule-based alphanumeric information in a visual/memory search task. The third experiment investigated the processing of static spatial pattern information within a visual/memory search task. This experiment also employed a subjective measurement technique to assess the workload associated with task performance under different mapping conditions. Finally, Experiment 4 investigated the effect of extensive training on spatial pattern information processing in a visual/memory search task that manipulated both memory and display load, and also evaluated the effect of whole versus part-task training on performance.

Experiment 1  
Development of Automatic Processing in a Memory Search Task  
Requiring the Processing of Complex Alphanumeric Rule-Based  
Information

Purpose

Some Air Force C<sup>2</sup> systems require the operator to rapidly process complex alphanumeric information in the form of the rule-based task type discussed above. These rules consist of the conjunction of an acronym or letter sequence that represents a system parameter and a range of numerical values associated with that parameter. Although the capability to automatize the processing of such rule-based alphanumeric information is of great potential importance to C<sup>2</sup> systems operators, the current literature offers little information on the automatic processing of such complex alphanumeric materials.

Therefore, the purpose of Experiment 1 was to investigate the effect of training under several stimulus-response mapping conditions on performance with a type of alphanumeric information processed by some Air Force system operators. This experiment employed a memory search paradigm based on the Sternberg (1966) procedure. This type of memory search, a component of many operator tasks in air weapons control and event detection systems, requires a rapid and accurate response.

The memory search task in this experiment used target and distractor sets which consisted of complex alphanumeric rules that included both a three-letter sequence (e.g., SNK, GLX) and a range of numerical values (e.g., 45-55, 25-35) associated with a particular letter sequence. For example, one rule might take the form of "SNK 45-55," while a second rule could be "GLX 25-35." These rules were the items in the memory set. A probe item consisted of a single conjunction of a letter sequence and numerical value that either represented an exemplar of the rule or did not. Thus, the probe item "SNK 47" is an exemplar of SNK

45-55 (the numerical value 47 falls within the specified range for SNK), whereas "SNK 37" is not (the numerical value 37 falls outside the specified range for SNK).

There are several levels of consistency within the present rule-based task. One level concerns the association between a rule and its exemplars. For example, in the "SNK 45-55" rule discussed above, a certain set of exemplars (e.g., SNK 47, SNK 49, SNK 51) are consistently mapped to that rule. To correctly respond to a test exemplar, the exemplar must be associated with the appropriate rule. Therefore, one important aspect of skill acquisition in this task is to associate a set of exemplars with the corresponding rule.

A second level of consistency in this task concerns the roles played by the rules and their exemplars across training trials. Under consistent or CM conditions, a rule can remain a target for an individual subject across training. Under inconsistent or VM conditions, a particular rule can serve as either a target or distractor across training trials.

Given the different levels of consistency in this task, a number of mapping conditions, representing different consistency combinations, can be identified. Thus, a task can be consistent at both the rule and rule/exemplar levels. In this instance, certain rules remain targets throughout training, and are consistently associated with the same exemplars across training trials. This task represents a pure CM condition. The consistency at both levels should not only facilitate the capability of subjects to respond consistently throughout training to any given rule, but should also facilitate the association of a particular exemplar set with the appropriate rule.

A second possibility is that a task can be inconsistent in its role as a target or distractor across trials, but consistent

at the rule/exemplar level (i.e., the same exemplars are associated with the same rules throughout training). This condition -- a hybrid VM/CM condition -- is VM at the level at which rules are targets/distractors across trials, but is CM at the level at which a particular exemplar set is associated with a particular rule. Considerable learning would be expected under this condition, because a major component of correct responding in the present task is associating an exemplar set with an appropriate rule.

Finally, it is possible for a task to be inconsistent at both levels. A rule can be inconsistent in its role as a target/distractor across trials. The consistency of association of an exemplar set with an appropriate rule can also be eliminated by manipulating the conjunction of the three-letter acronym and associated numerical values on a trial-by-trial basis. In this condition, the acronym SNK might be associated with the numerical range 44-54 on one trial (requiring a positive response to exemplars such as "SNK 46," "SNK 48," and "SNK 50"). However, on the next trial, SNK might be associated with the numerical range 28-38 (requiring a positive response to exemplars such as "SNK 30," "SNK 32," and "SNK 34"). Within this condition, rules are not only inconsistent in their roles as targets or distractors across training trials, but the consistency of association of a particular exemplar with a particular rule is also eliminated. Elimination of rule/exemplar consistency should preclude subjects from acquiring an association between rules and exemplars. Because it is inconsistent at both levels, this condition represents a pure VM condition.

Both pure CM and VM conditions, as well as a hybrid VM/CM condition, were included in this experiment. Under CM conditions, particular rules and their associated exemplars remained targets throughout training for an individual subject, whereas exemplars of other rules served as distractors across

training sessions. In the pure VM condition, rules and their associated exemplars alternated as either targets or distractors across training trials. In addition, the conjunction of the three-letter acronym with a range of numerical values varied from trial to trial, thereby precluding the association of exemplars with rules across trials. Within the hybrid VM/CM condition, rules varied in their roles as targets/distractors across trials. However, the conjunction of three-letter acronyms with particular numerical ranges remained consistent across trials, thereby permitting the association of exemplars with the appropriate rules.

The different levels of consistency present in this task reflect its complexity and mirror the same type of differences expected to be present in "real-world" tasks. Therefore, this rule-based task was considered ideal to meet the objectives of the current program.

A portion of this experiment, involving pure CM and hybrid VM/CM conditions, was conducted under a previous phase of the present program and reported by Eggemeier et al. (1991). The remaining portions were conducted under the current phase of the program. The final data set for the entire study is included herein to provide a single report of the completed experiment.

### Method

Subjects. Subjects were 40 University of Dayton students, paid \$4.00/hour for their participation. Subjects were awarded a bonus payment of \$1.00/hour for appearing on time for each scheduled experimental session. Sixteen subjects participated under the CM and under the VM/CM conditions; eight subjects participated under the VM condition.

Apparatus. The experiment was controlled with a Zenith Data Systems 248 computer. The computer presented stimuli, controlled

the timing of stimuli presentation, collected subject responses, and presented visual feedback at the completion of each trial and session. Subjects viewed alphanumeric stimuli on a Zenith ZCM-1490 high-resolution, thirteen-inch color monitor. Responses were made on the arrow keys located in the lower right-hand corner of a standard expanded IBM-compatible keyboard.

Procedure. Subjects performed a memory search task similar to the Sternberg (1966) paradigm. On each trial, a memory set of one to three alphanumeric rules was presented on the computer cathode-ray tube (CRT) screen. These rules remained on the screen until the subject pressed a designated key on the computer keyboard. When the key was pressed, a 4.5 mm x 4.3 mm fixation cross appeared in the middle of the screen for 500 ms. The fixation cross was replaced by a single test item displayed until either the subject responded or two seconds had elapsed.

Subjects were instructed to determine if the test item represented an exemplar of any of the previously presented rules. Subjects responded "yes" or "no" by pressing a labeled response button on the keyboard. Half the stimuli in each block of trials constituted exemplars of memory set rules; the other half did not. Measures of both reaction time and response accuracy were recorded. Each subject was instructed to respond as rapidly as possible while maintaining an accuracy level of 90 percent or higher within each session.

Visual feedback was provided to subjects at the completion of each trial. An incorrect response was followed by a "Wrong Response" message; a correct response was followed by a "Correct Response" message and the reaction time for that trial.

Summary feedback, presented to subjects at the completion of each block of trials, provided reaction time and accuracy performance levels from the completed trial block. Additionally, summary feedback concerning mean reaction times and accuracy

levels was provided to subjects at the completion of each session. A written tally of mean reaction time and accuracy levels across sessions was maintained to aid subjects in tracking their progress throughout the course of training.

Subjects participated in the experiment for a total of four days. Four training sessions, which consisted of ten blocks of 20 trials each, were completed each day. This resulted in 800 training trials every day, for a total of 16 sessions of 3200 training trials for the entire experiment.

Stimulus Materials. Each alphanumeric rule consisted of a three-letter sequence associated with a range of numerical values. These rules were intended to represent one type of complex alphanumeric information processed by operators of certain Air Force systems. As noted above, these systems require the operator to rapidly and accurately process alphanumeric rules associated with particular system parameters.

Two sets of letter sequences composed of four stimuli each were chosen from the 50-percent association value letter sequences in the Underwood and Schultz (1960) norms. Sequences in each set were chosen to be highly distinguishable from one another such that no sequence included a letter that appeared in the same serial position in another sequence. Therefore, the first, second, and third letter of each sequence differed from the letters in the corresponding serial position in the other sequences. These sets were chosen to minimize any similarity or potential confusability between the letter sequences intended to represent the code types used for C<sup>2</sup> system parameters.

Each letter sequence set was paired with two numerical ranges to develop two alphanumeric rules for each letter sequence. For example, the letter sequence DXR was paired with the numerical ranges 15-25 and 25-35 to form two rules (i.e.,

DXR 15-25, DXR 25-35) that used the same letter designator and demonstrated minimal overlap in their numerical values. Four pairs of such rules were developed for one rule set designated "A," and four additional pairs were developed for a second rule set designated "B." Half the CM and VM/CM subjects were trained with the Rule Set A; the remaining CM and VM/CM subjects were trained with Set B.

Two sets of positive exemplars (targets) and two sets of negative exemplars (distractors) were specified for each rule. Each exemplar set included five numerical values. For positive exemplars, each value fell within the specified range for the rule; for negative exemplars, each value fell either above or below the specified range for the rule. One set of positive exemplars contained only even numbers, while the alternate set included only odd numbers. The same was true of the negative exemplar sets.

Exemplar sets for rules bearing the same letter sequence were constructed such that there was overlap between the positive exemplars of one rule and the negative exemplars of another. For example, DXR 18 represented a positive exemplar for the rule "DXR 15-25" and a negative exemplar for the rule "DXR 25-35." Positive and negative exemplar sets were constructed such that four items in the positive set for one rule were represented in the negative set for the corresponding rule with the same letter sequence designator, and vice versa. Appendix A includes an example of a complete rule set.

The memory sets for subjects in the CM group included only one of the two rules from each pair with a common letter sequence designator. Therefore, CM subjects could consistently respond to any individual exemplar. For a subject whose memory set contained the rule "DXR-25," a positive response was always appropriate for the exemplar "DXR 18," and a negative response was always appropriate for "DXR 28."

VM/CM subjects, on the other hand, received on different trials both rules that shared a common letter designator. For these subjects, a positive response to "DXR 18" was correct if the memory set included the "DXR 15-25" rule, but was incorrect if the memory set included the "DXR 25-35" rule on that particular trial. Both CM and VM/CM subjects dealt with the same number of rules during training; the principal difference was that the VM/CM subjects had each rule explicitly stated in the memory set for different trials. In essence, CM subjects had to learn to respond positively to exemplars of "DXR 15-25" and negatively to exemplars of "DXR 25-35," even though the latter never explicitly appeared in the memory set. VM/CM subjects also dealt with both of these rules but had them explicitly presented in the memory set on different trials.

The VM condition utilized the same three-letter sequence sets and numerical values that were employed in the other two conditions. However, in this condition, the conjunction of the three-letter sequence and numerical value associated with it varied randomly from trial to trial. As noted above, this condition was included to eliminate the consistency that existed between the exemplars and rules in the VM/CM condition.

### Design

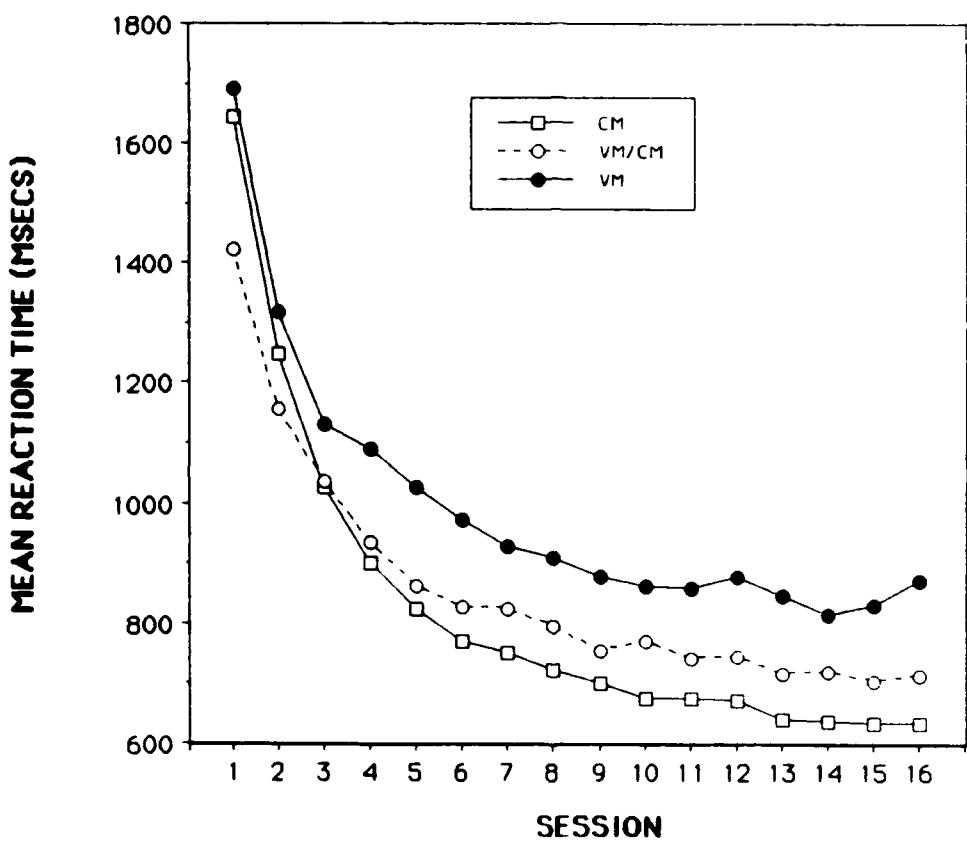
Three independent variables were included in the design: (a) target/distractor mapping, (b) memory set size, and (c) training sessions. Target/distractor mapping was either pure CM, pure VM, or hybrid VM/CM and represented a between-subjects variable. Sixteen subjects were assigned to the pure CM group, sixteen to the hybrid VM/CM group, and eight to the pure VM group. In the CM condition, one member of each rule pair sharing a common letter designator served as targets throughout training for an individual subject. Negative exemplars were drawn from a designated set that represented the alternate rule sharing the

common letter designator. In the hybrid VM/CM condition, exemplars of rules that shared a common letter designator served as both targets and distractors across blocks of trials. In the pure VM condition, the same sets of letter designators and numerical ranges that were employed in the other two mapping conditions were used, but the conjunction of letter designators and numerical values varied randomly from trial to trial. Memory set size was manipulated within trial blocks in each group and consisted of one to three sequences. Each group completed 16 sessions of practice trials across the four days of training.

### Results

Reaction Time. Mean reaction time, as a function of mapping condition and training sessions, is illustrated in Figure 1-1. The means presented are based on correct responses. As depicted in the figure, training sessions had an effect on reaction time in each mapping condition -- reaction time improved in each condition. Beginning with Session 4, an ordering of mapping conditions emerged in which the CM condition resulted in the fastest reaction times, the VM condition produced the slowest, and the hybrid VM/CM condition produced reaction times between the two pure mapping conditions.

A 3 x 3 x 16 Analysis of Variance (ANOVA) was performed on the reaction time data to analyze the effects of mapping condition (CM, VM/CM, VM), memory set size (1-3), and training session (1-16). Mapping condition was a between-subjects variable in this analysis, whereas memory set size and training session were within-subjects variables. This analysis indicated that the main effects of mapping condition ( $F(2,37) = 3.42$ ,  $p < .05$ ,  $MS_e = 1139087.9$ ), memory set size ( $F(2,74) = 347.16$ ,  $p < .001$ ,  $MS_e = 92053.38$ ), and training sessions

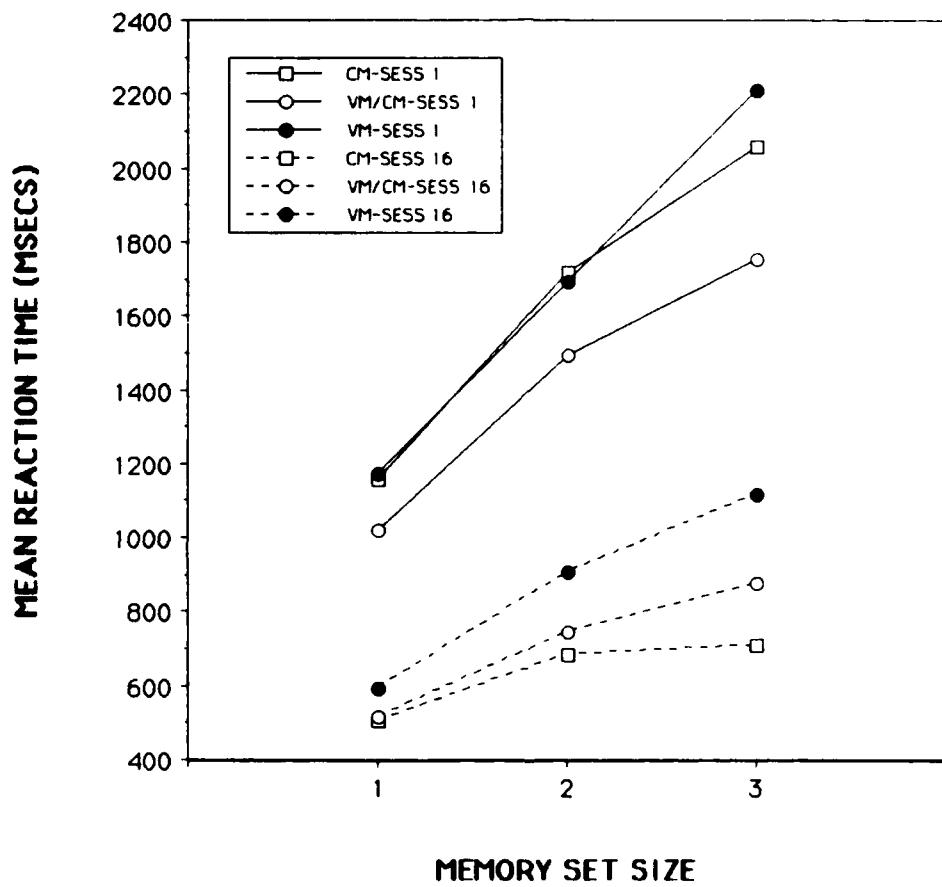


**Figure 1-1.** Mean Reaction Time as a Function of Mapping Condition and Training Session.

( $F(15,555) = 105.08, p < .001, MS_e = 56079.29$ ) were significant. In addition, the analysis showed that the interactions of mapping condition and memory set ( $F(4,74) = 9.56, p < .01$ ), mapping condition and training sessions ( $F(30,1110) = 32.44, p < .01$ ), and memory set and training sessions ( $F(30,555) = 1.52, p < .05$ ) were reliable. The three-way interaction of mapping condition, training sessions, and memory set ( $F(60, 1110) = 1.60, p < .01$ ) was also significant.

Figure 1-2 shows the effect of memory set size on reaction time in each mapping condition during Sessions 1 and 16. As seen in the figure, memory set had a marked effect on performance under all three conditions during Session 1, and differences between groups were quite consistent across memory set sizes. However, at the conclusion of training, memory set size had less effect on performance, and differences between the groups tended to become more pronounced at the higher memory set sizes. To investigate the reliable three-way interaction, a  $3 \times 3$  ANOVA which evaluated the effect of mapping condition (CM, VM/CM, VM) and memory set size (1, 2, 3) was performed at Sessions 1 and 16. These analyses indicated that there was a main effect of memory set size at Session 1 ( $F(2,74) = 133.32, p < .001, MS_e = 54162$ ), but no main effect of mapping condition ( $F(2,37) = 1.31, p > .05, MS_e = 641822.74$ ), and no reliable interaction of mapping condition and memory set ( $F(4,74) = 1.43, p > .05$ ). Tukey Honestly Significant Difference (HSD) post-hoc comparison tests (Kirk, 1982) showed that the reaction times associated with all memory set sizes differed reliably ( $p < .05$ ).

The Session 16 analysis revealed that the main effect of memory set ( $F(2,74) = 165.86, p < .001, MS_e = 7450.95$ ) continued to be reliable, but also showed a significant main effect of mapping condition ( $F(2,37) = 9.51, p < .001, MS_e = 47693.43$ ) and a reliable interaction of mapping condition and memory set ( $F(4,74) = 9.94, p < .001$ ). The significant interaction was followed by a test of the mapping condition effect at each memory



**Figure 1-2.** Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Training Session.

set size. These analyses showed that the effect of mapping condition was significant at memory set size one ( $F(2,37) = 3.28$ ,  $p < .05$ ,  $MS_e = 6191.56$ ), at memory set size two ( $F(2,37) = 6.69$ ,  $p < .05$ ,  $MS_e = 20250.49$ ), and at memory set size three ( $F(2,37) = 12.33$ ,  $p < .001$ ,  $MS_e = 36153.29$ ). Contrasts conducted at each memory set level revealed that the CM condition differed from the VM condition at memory set sizes one ( $F(1,37) = 5.93$ ,  $p < .05$ ,  $MS_e = 6191.56$ ), two ( $F(1,37) = 13.30$ ,  $p < .005$ ,  $MS_e = 20250.49$ ), and three ( $F(1,37) = 24.39$ ,  $p < .001$ ,  $MS_e = 36153.29$ ). The hybrid VM/CM condition also differed from the VM condition at memory set sizes one ( $F(1,37) = 4.90$ ,  $p < .05$ ), two ( $F(1,37) = 7.02$ ,  $p < .05$ ), and three ( $F(1,37) = 8.44$ ,  $p < .01$ ). However, although the CM and hybrid VM/CM conditions differed at memory set size three ( $F(1,37) = 6.20$ ,  $p < .05$ ), they did not do so at memory set size one ( $F(1,37) = 0.07$ ,  $p > .05$ ) or two ( $F(1,37) = 1.49$ ,  $p > .05$ ).

In addition to reaction time differences between mapping conditions, a second criterion that can be applied to assess automatic processing development is a greater reduction in the task demand effect within the CM group versus the VM/CM and VM groups. As shown in Figure 1-2, memory set size had a substantial effect on performance in each mapping condition during the first training session. However, at the conclusion of training, the effect of memory set on reaction time had been somewhat attenuated in the CM group, while memory set size continued to show a more marked effect on VM/CM and VM group performance.

To characterize the effects of memory set size reductions on performance in each group, slopes of the functions depicted in Figure 1-2 were computed. Within the CM group, the slope of the Session 1 function was 450 ms and the slope of the Session 16 function was 102 ms. In the hybrid CM/VM group, comparable slopes were 368 ms and 181 ms, respectively. Within the VM group, the slope of the Session 1 function was 519 ms, and the

slope of the Session 16 function was 263 ms. Thus, at the conclusion of training, the slope of the VM function was more than twice that of the CM function, while the slope of the hybrid VM/CM function fell almost midway between these two extremes. This type of difference is consistent with some level of automatic processing development within the CM condition, and also reflects the considerable learning expected to occur within the hybrid VM/CM condition.

Accuracy of Responding. Figure 1-3 shows mean percent correct responses as a function of mapping condition and training session. As is clear from the figure, response accuracy was consistently high in all mapping conditions and approximated the 90-percent criterion level required of the subjects.

A  $3 \times 3 \times 16$  ANOVA, comparable to that performed on the reaction time data, was conducted on the percent correct responses. This analysis demonstrated no main effect of mapping condition ( $F(2,37) = 0.89$ ,  $p > .05$ ,  $MS_e = 39.48$ ), but did demonstrate that the main effects of memory set size ( $F(2,74) = 99.45$ ,  $p < .001$ ,  $MS_e = 63.63$ ) and training sessions ( $F(15,555) = 3.73$ ,  $p < .001$ ,  $MS_e = 18.38$ ) were significant. None of the interactions in this analysis were significant.

Analysis of the accuracy data reflects the fact that subjects in each mapping condition maintained response accuracies very close to the 90-percent correct performance criterion set at the beginning of the experiment. Performance in each condition first improved, then declined to more closely approximate the 90-percent criterion level as training sessions progressed. Feedback at the conclusion of each trial block emphasized that subjects should respond as quickly as possible while maintaining at least a 90-percent accuracy level. The tendency to approximate these levels with training most likely represents the effects of this feedback. Percent-correct performance also declined with increased memory set size in all three mapping

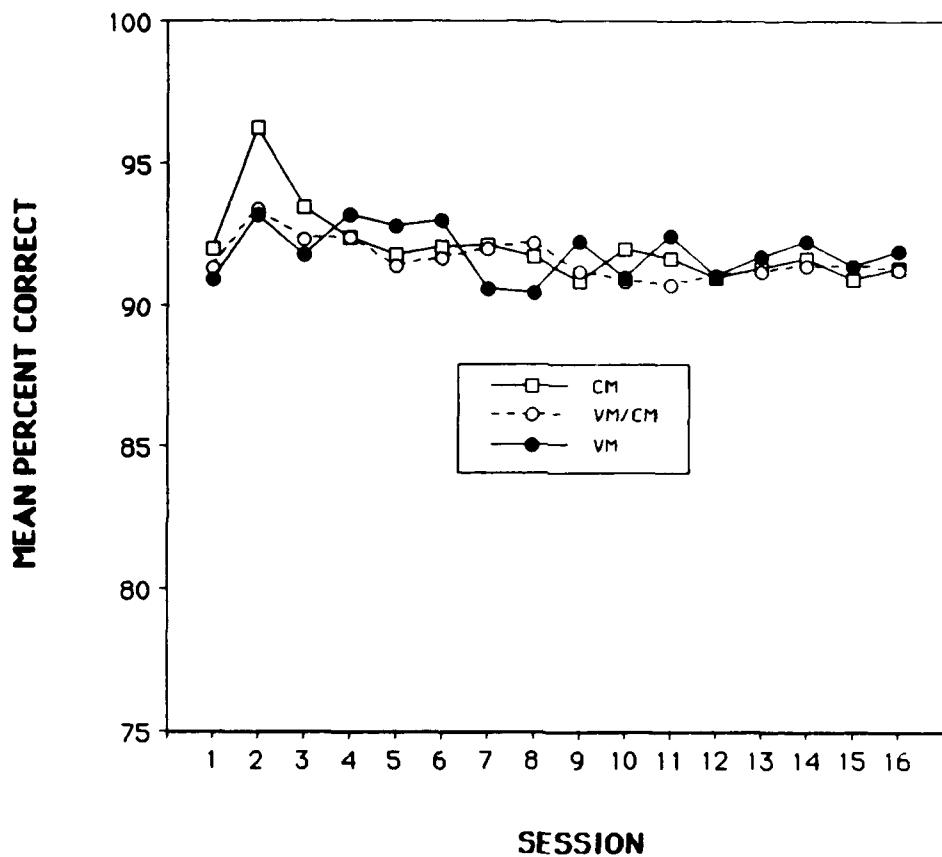


Figure 1-3. Mean Percent Correct as a Function of Mapping Condition and Training Session.

conditions. Most importantly, the accuracy data provide no basis to infer the presence of a speed/accuracy tradeoff that would affect interpretation of the reaction time mapping condition results discussed above.

### Discussion

The results of this experiment demonstrate reliable differences between the pure CM and pure VM conditions which are consistent with some level of automatic processing development within the CM condition. CM reaction time performance was superior to VM performance and showed a greater attenuation of the effect of memory set size. Therefore, the present results indicate that automatic processing can be developed with complex alphanumeric materials of the type used here within a memory search paradigm.

In addition to demonstrating reliable differences between the pure CM and VM conditions, the present results also indicate that the levels of reaction time performance achieved within the hybrid VM/CM condition fell between those demonstrated by the pure mapping conditions. As noted in the introduction, the hybrid VM/CM condition was consistent at the level of the exemplar association with appropriate rules; therefore, more marked performance improvements were expected in this condition than in the pure VM condition. On the other hand, the hybrid VM/CM condition was inconsistent with respect to the target/distractor role played by rules across trials. Therefore, the performance levels associated with this condition were not expected to equal those achievable with training in the pure CM condition. This proved to be the case under the highest memory load condition, although CM and VM/CM performance did not differ reliably at the lower two memory set size conditions. Previous work in this series (Eggemeier et al., 1990, 1991) and in other investigations (Fisk and Schneider, 1983) has repeatedly demonstrated that automatic processing effects are most

pronounced at higher memory set sizes within the type of search paradigm used here. Therefore, the present results can be interpreted as consistent with automatic processing development at the rule level within the pure CM condition.

The present pattern of results is of practical importance to eventual applications of automatic processing to C<sup>2</sup> systems. The data demonstrate that automatic processing can be developed with a type of rule-based memory search function that represents a major component of some C<sup>2</sup> operator tasks. The results also demonstrate that subjects are capable of utilizing the different levels of consistency present in complex alphanumeric search tasks such as the present one. This, in turn, suggests that training programs can be designed to capitalize on subcomponent consistencies, even if the task or function is not completely consistent. This latter result is of great potential importance for eventual application to complex C<sup>2</sup> operator tasks. The majority of such tasks will not likely demonstrate complete consistency and will rely on operator ability to utilize consistency at the subcomponent level in order to realize some improvement in performance with training.

Experiment 2  
Development of Automatic Processing in a Visual/Memory Search  
Task Requiring the Processing of  
Complex Alphanumeric Rule-Based Information

Purpose

Air Force C<sup>2</sup> systems operators can be required to rapidly process complex alphanumeric information in the form of the rule-based type of task discussed above. These rules consist of the conjunction of an acronym or letter sequence that represents a system parameter and range of numerical values associated with that parameter. Experiment 1 demonstrated evidence of automatic

then provided ratings on the next-to-the-last. Therefore, half the subjects rated the CM condition followed by the VM condition, while the remaining subjects rated the conditions in the reverse order.

In addition to the TLX ratings themselves, subjects also completed the TLX paired-comparison procedure at the conclusion of one of the training sessions. This procedure requires that subjects consider all possible pairs of the six workload dimensions in the TLX scale and indicate which dimension in each pair contributed more to his or her perception of the workload imposed by the hybrid visual/memory search task. Data from this paired-comparison procedure were used to weight the ratings on each dimension in order to combine them for each subject and derive an overall scale of the workload associated with task performance (Hart and Staveland, 1988).

Visual feedback was provided to subjects after each trial. An incorrect response was followed by an "Incorrect Response" message and the reaction time for that trial. A correct response was followed by a "Correct Response" message and the reaction time for that trial.

Summary feedback, provided at the completion of each block of trials, consisted of reaction time and accuracy performance levels from the trial block just completed. In addition to feedback at the completion of a block, summary feedback concerning mean reaction times and accuracy levels was provided to subjects at the completion of each session. Subjects maintained a written tally of mean reaction time and accuracy levels across blocks of trials to aid in tracking their progress throughout training.

Subjects participated in the experiment for a total of ten days. One training session (eight blocks of 40 trials) was completed each day. Half the blocks were CM blocks; the other

half were VM blocks (i.e., 160 CM training trials and 160 VM training trials each day). Thus, subjects received 1600 CM training trials and 1600 VM training trials during the ten days of the experiment.

Stimulus Materials. Each alphanumeric rule consisted of a three-letter sequence associated with a range of numerical values. These rules were intended to represent one type of complex alphanumeric information processed by operators of certain Air Force systems.

Four sets of letter sequences composed of four stimuli each were chosen from the 50-percent association value letter sequences in the Underwood and Schultz (1960) norms. Sequences in each set were chosen to be highly distinguishable from one another to ensure minimal overlap in the letters that appeared in each serial position across sequences.

Each letter sequence set was paired with two numerical ranges to develop two alphanumeric rules for each sequence. For instance, the letter sequence FLJ was paired with the numerical ranges 18-28 and 28-38 to form two rules (i.e., FLJ 18-28, FLJ 28-38) that used the same letter designator and demonstrated minimal overlap in their numerical values. Four pairs of such rules were developed for each of the four sets of rules employed in the experiment. One rule set served as CM material for a particular subject, while another set served as VM material for that subject. As noted above, assignment of rule sets was counterbalanced across subjects such that each set was employed an equal number of times under CM and VM conditions.

Two sets of positive exemplars (targets) and two sets of negative exemplars (distractors) were specified for each rule. Each exemplar set included five numerical values. For positive exemplars, each value fell within the specified range for the rule; for negative exemplars, each value fell either above or

below the specified range. One set of positive exemplars contained only even numbers, while the alternate set included only odd numbers. The same was true of negative exemplar sets.

Exemplar sets for rules bearing the same letter sequence were constructed such that there was overlap between the positive exemplars of one rule and the negative exemplars of another. For example, FLJ 20 represented a positive exemplar for the rule "FLJ 18-28," and a negative exemplar for the rule "FLJ 28-38." Positive and negative exemplar sets were constructed such that four items in the positive set for one rule were represented in the negative set for the corresponding rule with the same letter designator, and vice versa.

Under CM conditions, the memory sets included only one of the two rules from each pair that shared a common letter sequence designator. Subjects could therefore consistently respond to any individual exemplar under CM conditions. For example, for a subject whose memory set contained the rule "FLJ 18-28," a positive response was always appropriate for the exemplar "FLJ 20," and a negative response was always appropriate for the exemplar "FLJ 30."

Within VM conditions, subjects received both rules that shared a common letter designator on different trials. In a VM trial, a positive response to "FLJ 20" was correct if the memory set included the "FLJ 18-28" rule but incorrect if the memory set included the "FLJ 28-38" rule for that particular trial. Subjects dealt with the same number of rules in the VM and CM conditions during training, with the principal difference being that the VM condition involved the explicit statement of each rule in the memory set on different trials.

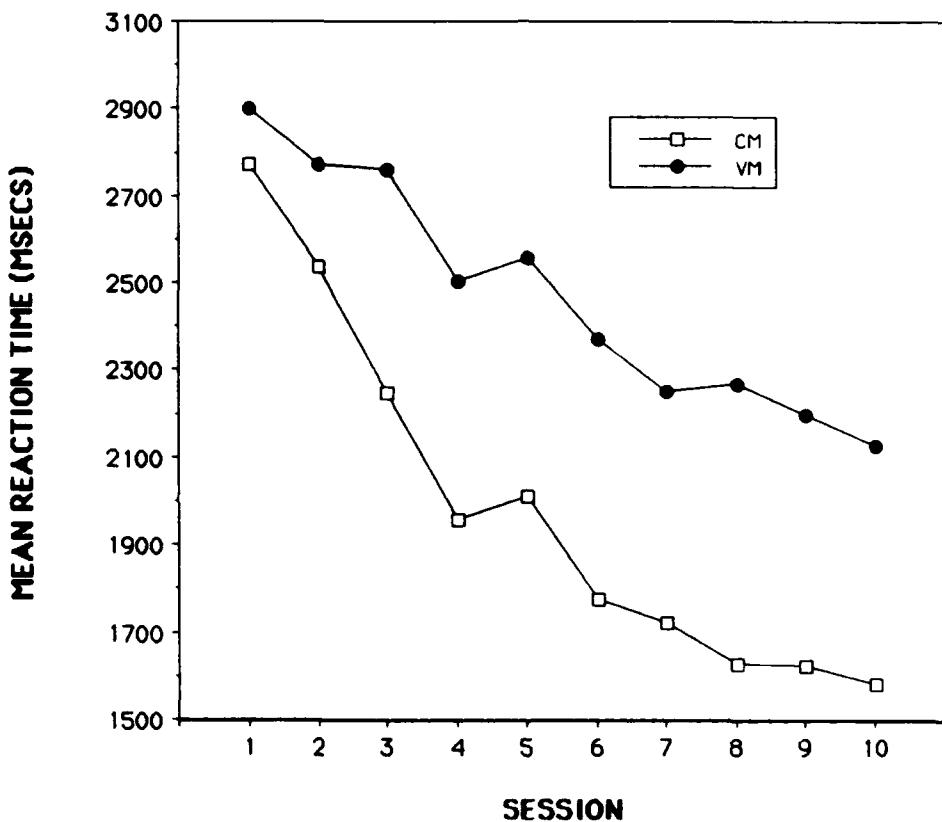
## Design

Three independent variables were included in the design: (a) target/distractor mapping, (b) memory set size, and (c) training sessions. Target/distractor mapping was either CM or VM, and represented a within-subjects variable. In the CM condition, one member of each pair of rules sharing a common letter designator served as targets throughout training for an individual subject. Negative exemplars were drawn from a designated set that represented the alternate rule that shared the common letter designator. In the VM condition, exemplars of rules that shared a common letter designator served as both targets and distractors across blocks of trials. Memory set size was manipulated within blocks of trials in each group and consisted of one to four rules.

## Results

Reaction Time. Mean reaction time as a function of mapping condition and training sessions is illustrated in Figure 2-1. The means presented in Figure 2-1 are based on correct responses. As noted in the figure, training sessions had an effect on reaction time in each mapping condition, and performance improved with training in each condition. Reaction times associated with the CM condition were consistently lower than those associated with the VM condition across training sessions.

A 2 x 4 x 10 ANOVA was performed on the reaction time data to analyze the effects of mapping condition (CM versus VM), memory set size (1-4), and training sessions (1-10). Mapping condition, memory set size, and training session were all within-subjects variables. This analysis demonstrated that the main effects of mapping condition ( $F(1,7) = 27.31$ ,  $p < .005$ ,  $MSe = 1382675.0$ ), memory set size ( $F(3,21) = 306.39$ ,  $p < .001$ ,  $MSe = 177250.64$ ), and training sessions ( $F(9,63) = 30.01$ ,

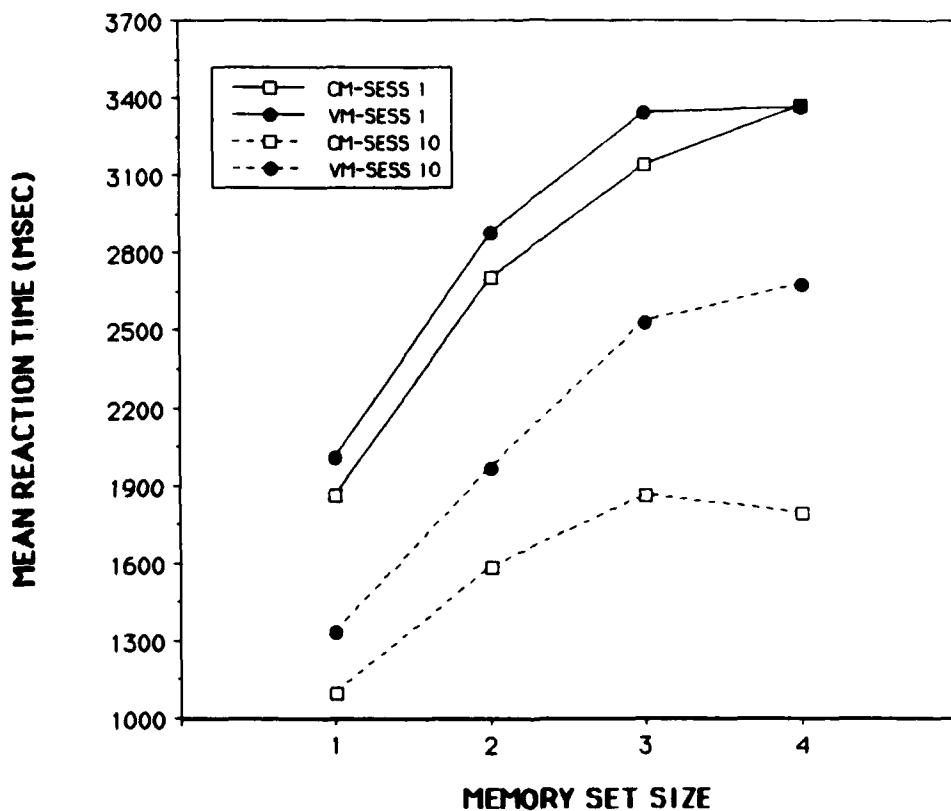


**Figure 2-1.** Mean Reaction Time as a Function of Mapping Condition and Training Session.

$p < .001$ ,  $MSe = 243698.89$ ) were significant. The analysis also showed that the interactions of mapping condition and memory set ( $F(3,21) = 31.09$ ,  $p < .001$ ,  $MSe = 83537.47$ ), mapping condition and training sessions ( $F(9,63) = 7.60$ ,  $p < .001$ ,  $MSe = 57805.40$ ), and memory set and training sessions ( $F(27,189) = 2.73$ ,  $p < .001$ ,  $MSe = 39840.18$ ) were reliable. In addition, the three-way interaction of mapping condition, training sessions, and memory set size ( $F(27,189) = 3.81$ ,  $p < .001$ ,  $MSe = 27530.68$ ) was significant.

Figure 2-2 shows the effect of memory set size on reaction time in each mapping condition during Session 1 and Session 10. As illustrated by the figure, memory set had a substantial effect on performance under both mapping conditions during Session 1. At the conclusion of training, however, memory set size exerted less of an effect on reaction time, particularly in the CM condition. The significant three-way interaction was investigated with separate  $2 \times 4$  ANOVAs which examined the effect of mapping condition (CM versus VM) and memory set (1-4) at Sessions 1 and 10. These analyses indicated that during Session 1, there was a significant effect of memory set size ( $F(3,21) = 100.86$ ,  $p < .001$ ,  $MSe = 66848.10$ ), no reliable effect of mapping condition ( $F(1,7) = 5.01$ ,  $p > .05$ ,  $MSe = 52115.14$ ), and no significant interaction of mapping condition and memory set size ( $F(3,21) = 0.71$ ,  $p > .05$ ,  $MSe = 50920.60$ ).

The Session 10 analysis indicated that the main effect of memory set ( $F(3,21) = 77.10$ ,  $p < .001$ ,  $MS_e = 46887.55$ ) was significant once again. It also demonstrated a significant main effect of mapping condition ( $F(1,7) = 26.90$ ,  $p < .005$ ,  $MS_e = 175286.14$ ) and a reliable interaction of mapping condition and memory set ( $F(3,21) = 11.83$ ,  $p < .001$ ,  $MS_e = 27622.38$ ). To evaluate the significant interaction, tests of the memory set size effect were conducted at each mapping condition. These analyses showed that the memory set effect was significant within both the CM ( $F(3,21) = 24.32$ ,  $p < .001$ ,  $MS_e = 39751.92$ ) and VM



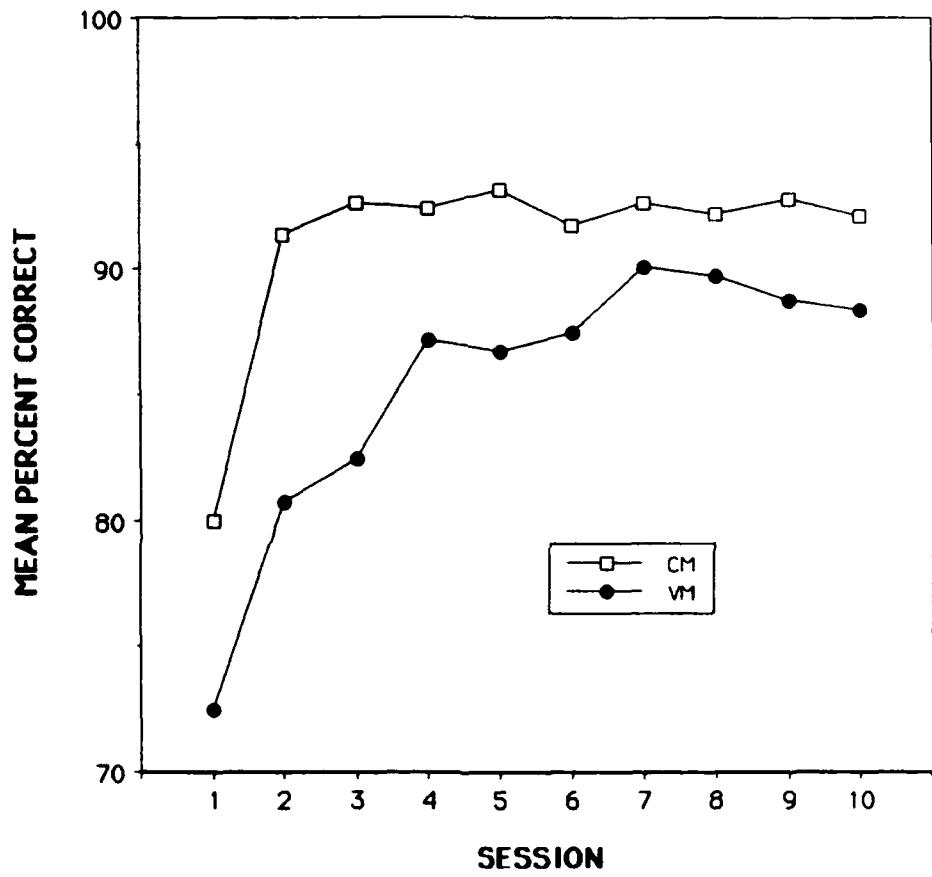
**Figure 2-2.** Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Training Session.

( $F(3,21) = 85.58$ ,  $p < .001$ ,  $MS_e = 34758.01$ ) conditions. Eta squared analyses of effect size indicated that, as expected, the effect of memory set within the CM condition (.777) was smaller than the effect of memory set size within the VM condition (.924). This difference is consistent with some level of automatic processing development within the CM condition.

To characterize the reduction in the effect of memory set size on performance, slopes of the functions depicted in Figure 2-2 were computed. Within the CM condition, the slope of the Session 1 function was 498.5 ms, and the slope of the Session 10 function was 238.4 ms. Within the VM condition, the slope of the Session 1 function was 452.5 ms and remained stable at 458.2 ms in Session 10. Therefore, at the conclusion of training, there was a 52 percent reduction in the slope within the CM condition, while the slope of the VM condition remained stable.

Accuracy of Responding. Figure 2-3 shows mean percent correct responses as a function of mapping condition and training session. As illustrated in the figure, response accuracy fell well below the stipulated 90-percent criterion level in both mapping conditions during Session 1 but markedly improved within the CM condition which met or exceeded the criterion level in all subsequent sessions. VM performance also improved with sessions but did not attain the levels achieved in the CM condition.

A  $2 \times 4 \times 10$  ANOVA, comparable to the one performed on the reaction time data, was conducted on the percent correct responses. This analysis demonstrated significant main effects of mapping condition ( $F(1,7) = 44.12$ ,  $p < .001$ ,  $MS_e = 118.87$ ), memory set size ( $F(3,21) = 55.00$ ,  $p < .001$ ,  $MS_e = 183.72$ ), and training sessions ( $F(9,63) = 19.11$ ,  $p < .001$ ,  $MS_e = 68.59$ ). The interactions of mapping condition and training sessions ( $F(9,63) = 6.03$ ,  $p < .001$ ,  $MS_e = 22.74$ ), memory set and training sessions ( $F(27,189) = 8.90$ ,  $p < .001$ ,  $MS_e = 32.21$ ), and mapping condition and memory set ( $F(3,21) = 33.40$ ,  $p < .001$ ,  $MS_e = 50.15$ )

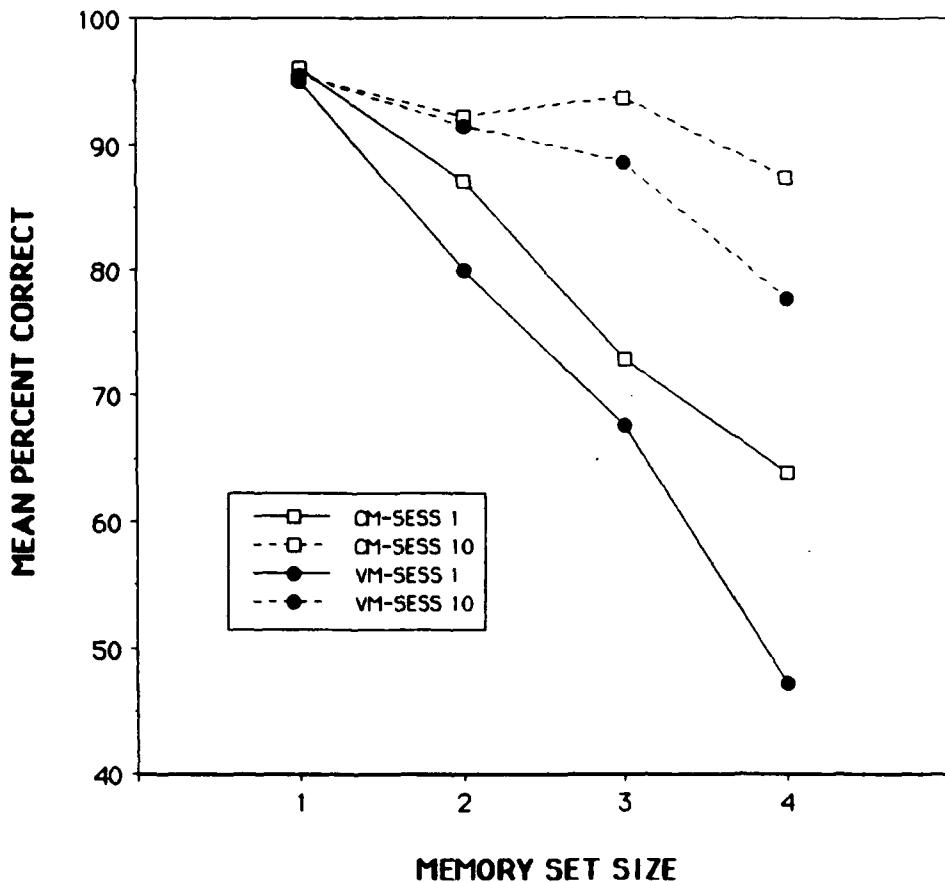


**Figure 2-3.** Mean Percent Correct as a Function of Mapping Condition and Training Session.

were also significant, as was the three-way interaction of mapping condition, memory set, and training sessions ( $F(27,189) = 2.62$ ,  $p < .001$ ,  $MS_e = 24.45$ ).

Figure 2-4 shows mean percent correct as a function of mapping condition and memory set size in Sessions 1 and 10. As shown in the figure, memory set influenced performance accuracy under CM and VM conditions in both sessions, with the CM condition demonstrating consistently superior performance. Percent correct performance was quite low at the higher memory set sizes under both conditions in Session 1, but was particularly low in the VM condition. These initial levels of performance reflect the difficulty of the visual/memory search rule task. As expected, the effects of memory set size were more pronounced in Session 1 than in Session 10. Also, there is evidence of the attenuation of the initial memory set size effect with training. This attenuation appears somewhat more marked in the VM as compared to the CM condition. As noted above, initial performance in the VM condition was very low. Although VM performance did not reach CM performance levels by Session 10, the initial performance discrepancy between the two mapping conditions at the larger memory set sizes was somewhat reduced with training.

To investigate the reliable three-way interaction of mapping condition, memory set, and training sessions, analyses of mapping condition and memory set effects were performed within Sessions 1 and 10. These analyses indicated that, within Session 1, the main effects of mapping condition ( $F(1,7) = 25.63$ ,  $p < .001$ ,  $MS_e = 35.41$ ) and memory set ( $F(3,21) = 165.67$ ,  $p < .001$ ,  $MS_e = 28.66$ ) were significant, as was the interaction between the two ( $F(3,21) = 5.20$ ,  $p < .001$ ,  $MS_e = 33.13$ ). The Session 10 analysis demonstrated a similar pattern and showed that the main effects of mapping condition ( $F(1,7) = 29.06$ ,  $p < .001$ ,  $MS_e = 7.87$ ) and memory set ( $F(3,21) = 9.38$ ,  $p < .001$ ,  $MS_e = 50.75$ ) were once again reliable, as was the interaction of the two



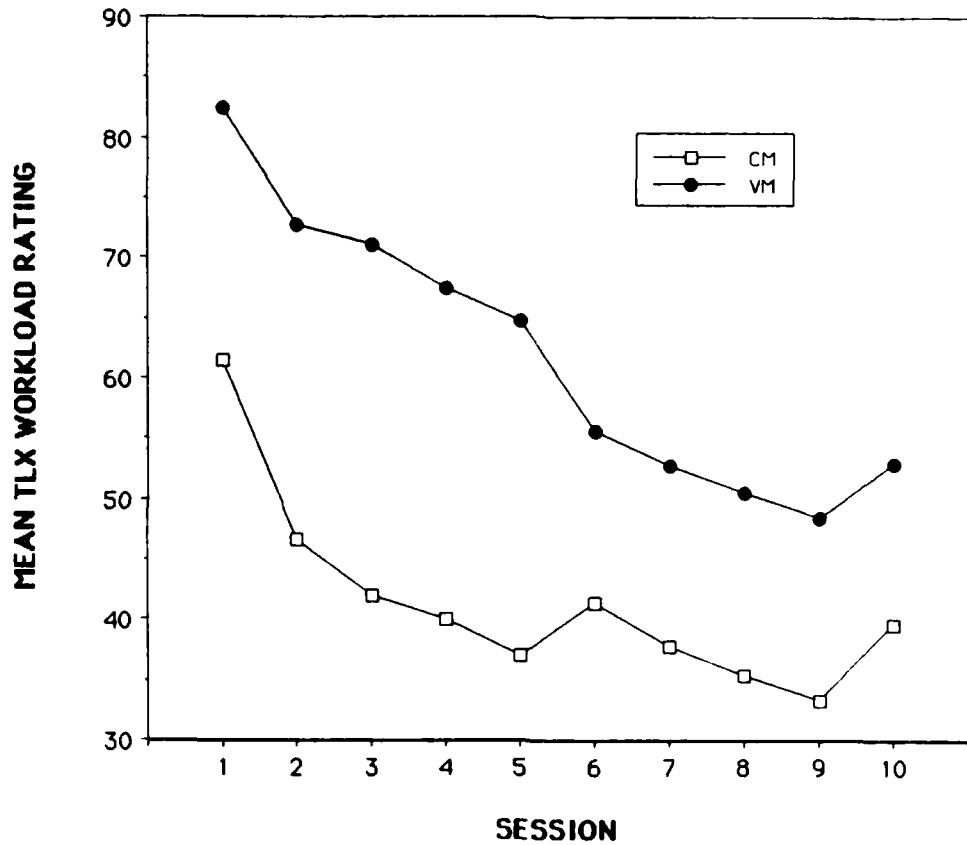
**Figure 2-4.** Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Training Session.

( $F(3,21) = 3.39$ ,  $p < .001$ ,  $MS_E = 23.91$ ). Eta squared analyses of the size of the interaction effects indicated that the size of the mapping condition and memory set interaction was larger in Session 1 (.426) than in Session 10 (.326). This difference in the mapping condition and memory set interaction size reflects the previously described tendency for the initial discrepancy between CM and VM performance to have been somewhat attenuated at Session 10, and serves as the basis for the noted three-way interaction.

Therefore, accuracy results indicate that CM performance was superior to VM performance across memory sets and training sessions. Thus, the accuracy data provide no evidence of a speed/accuracy tradeoff that would affect interpretation of reaction time mapping condition results discussed above.

NASA TLX Workload Ratings. In addition to the performance data, subjective workload ratings that resulted from the NASA TLX Scale were analyzed as well. Figure 2-5 shows mean TLX workload ratings as a function of mapping condition and training sessions. The ratings illustrated in this figure are based on the overall workload rating, which is derived from the TLX procedure. This overall workload represents the weighted combination of ratings from six subscales (Hart and Staveland, 1988), each of which stands for one of the TLX workload dimensions. Several trends can be noted in the figure. The most notable is that the workload associated with the CM condition was consistently lower than the workload associated with the VM condition. The figure also illustrates that workload ratings decreased as a function of training in both mapping conditions, and these decreases were somewhat more marked in the VM versus the CM condition.

A  $2 \times 10$  ANOVA was performed on the data illustrated in Figure 2-5 to investigate the effect of mapping condition and training sessions on the rated workload associated with performance of the hybrid visual/memory search task. This



**Figure 2-5.** Mean TLX Workload Ratings as a Function of Mapping Condition and Training Session.

analysis revealed that the main effects of mapping condition ( $F(1,7) = 38.56$ ,  $p < .001$ ,  $MS_e = 432.71$ ) and training sessions ( $F(9,63) = 10.37$ ,  $p < .001$ ,  $MS_e = 133.24$ ) were significant, as was the interaction of mapping condition and training sessions ( $F(9,63) = 4.01$ ,  $p < .001$ ,  $MS_e = 42.98$ ). To investigate this interaction, tests of the effects of mapping condition were conducted within Session 1 and Session 10. These analyses showed that the effect of mapping condition was reliable within both Session 1 ( $F(1,7) = 41.16$ ,  $p < .001$ ,  $MS_e = 42.86$ ) and Session 10 ( $F(1,7) = 24.01$ ,  $p < .001$ ,  $MS_e = 29.25$ ). Eta squared analyses indicated that the size of the mapping condition effect was somewhat greater during Session 1 (.855) than during Session 10 (.774). Thus, the mapping condition and training sessions interaction in the overall analysis reflects the tendency for larger reductions in VM versus CM workload with training. This effect may be attributable to the fact that CM workload was substantially lower than VM workload during the initial session; therefore, CM workload may have demonstrated a more restricted range of reduction than was true in the VM condition.

### Discussion

The results of this experiment indicate that some level of automatic processing was achieved within the CM mapping condition, as evidenced by the superior performance under the CM versus the VM condition in both reaction time and accuracy analyses. At the conclusion of training, the effect of memory set size on reaction time was also attenuated in the CM condition, but remained stable within the VM condition. This attenuation is also consistent with the development of some level of automatic processing in the CM condition. Therefore, the present results extend those obtained with a memory search task in Experiment 1 to the visual/memory search task employed in this experiment. As noted above, visual/memory search processes represent important components of many C<sup>2</sup> operator tasks, and the present data indicate that the processing of complex alphanumeric

information within this type of search is open to the development of automatic processing with training.

In addition to performance differences between the CM and VM conditions, the present results also indicate that the workload associated with visual/memory search task performance was lower in the CM versus the VM condition. This result is also consistent with the development of automatic processing in the CM condition. The lower workload associated with CM performance is of considerable potential importance to C<sup>2</sup> operators who can be required to process large volumes of information. Lower workload levels can be associated with improved timesharing efficiency; and thus, the present result is potentially significant for the performance levels that could be achieved by C<sup>2</sup> operators under high workload timesharing conditions. Previous work (Reid, Shingledecker, and Eggemeier, 1981) has demonstrated a high correlation between rated workload and the capability of subjects to perform a concurrent secondary task. If this same relationship were to hold true in the present task, the lower workload ratings would indicate that CM versions of the rule-based task could be timeshared more effectively with an additional task than would the VM version of the rule-based task. The relationship between the rated workload in this task and the capability to timeshare additional alphanumeric tasks represents an important area for future research.

Experiment 3  
Development of Automatic Processing in a Visual/Memory Search  
Task with Spatial Pattern Information

Purpose

Experiments 1 and 2 demonstrated evidence of automatic processing with complex, rule-based alphanumeric materials in memory search and visual/memory search paradigms, respectively. The purpose of this third experiment was to investigate the performance levels which could be achieved in CM and VM conditions within a visual/memory search task that required processing of static spatial pattern information. The visual/memory search task requires that a number of target patterns be held in memory and that subsequently presented test patterns be rapidly and accurately classified as members or non-members of the set. As described previously, this type of visual/memory search of spatial pattern information is a central component of important operator functions in several Air Force C<sup>2</sup> systems, such as air weapons control.

Eggemeier et al. (1990, 1991) have reported evidence of automatic processing development with static spatial patterns in memory search paradigms that involved presentation of a memory set and a subsequent probe item which was classified as either a target or distractor pattern. The present experiment differed from previous work in this series in several ways. First, the current experiment employed a visual/memory search paradigm that incorporated both the memory search component present in previous experiments and a visual search component. This type of combined search is characteristic of operator functions within several C<sup>2</sup> systems. In addition, the static spatial patterns used in the present experiment were more complex than those used in the previous experiments. Patterns employed in the current experiment were composed of six to seven elements and depicted more elaborate movement patterns than the five-element patterns used in previous research; therefore, they could be considered

somewhat more representative of C<sup>2</sup> system demands than the patterns used in earlier experiments. A third difference between this experiment and previous work in the series concerned the nature of the VM condition. In previous experiments, the memory set under VM conditions had changed on a trial-by-trial basis; therefore, a new memory set was associated with each probe processed by the subject. In the present experiment, the memory set was changed for CM and VM subjects after every ten trials. Consequently, some level of consistency was incorporated into the VM condition, making it a hybrid as opposed to a pure VM condition. Such consistency was considered a likely variant on pure VM conditions in operational environments. The present paradigm permitted investigation of CM and VM performance differences under the hybrid VM condition with spatial pattern information.

An additional purpose of this experiment was to assess the subjective workload associated with CM and VM performance under varying memory set sizes. One characteristic of automatic processing, important to eventual Air Force C<sup>2</sup> systems applications, is a reduction in the workload associated with CM performance. This reduction has been shown -- in some previous work (e.g., Vidulich and Pandit, 1986) with semantic category memory search -- to take the form of an attenuation of differences in rated workload associated with increases in memory set size. An objective of this experiment was to determine whether or not such an attenuation would also be found under CM versus VM conditions with spatial pattern information in a visual/memory search task. As in Experiment 2, the NASA-TLX procedure (Hart and Staveland, 1988) was used to assess the subjective workload associated with CM and VM performance.

## Method

Subjects. Sixteen subjects, between 18 and 30 years of age, participated in the experiment. They were paid \$3.75/hour for participation. Subjects were awarded a bonus of \$1.25/hour for appearing on time for each scheduled experimental session.

Apparatus. The experiment was controlled with a Zenith Data Systems 248 computer. The computer was programmed to present stimuli, control the timing of stimulus presentation, and collect subject responses. Subjects viewed spatial pattern stimuli on a Zenith ZCM-1490, high-resolution, thirteen-inch color monitor. Responses were made on the numeric keypad located in the lower right-hand corner of a standard expanded IBM-compatible keyboard. Auditory feedback concerning performance was presented to subjects through the speakers on the Zenith computers.

Procedure. Subjects performed a visual/memory search task similar to a paradigm utilized by Strayer and Kramer (1990). On each block of ten trials, subjects were shown a memory set consisting of either two or four spatial patterns on the CRT screen. These spatial patterns remained on the screen for thirty seconds or until the subject pressed a designated key. The memory set was replaced on the screen by the first of ten probe items. Each probe item consisted of two spatial patterns, one of which was a member of the memory set. The patterns in each probe were presented adjacent to one another, such that one occupied a position on the left and the other occupied a position on the right. Each probe subtended a horizontal visual angle of approximately 6.9 degrees for a subject seated in the normal position with respect to the display. A probe remained on the screen for five seconds or until the subject responded. If more than five seconds elapsed without a subject response, the probe was removed from the screen and that trial was scored as an incorrect response. The inter-probe interval was 500 ms. Each session included an equal number of blocks of trials of memory

set size two and memory set size four. These blocks alternated with one another. Half the subjects completed a block of memory set size four trials followed by a block of memory set size two trials. The remaining subjects completed the trials in the opposite order.

Subjects were instructed to rapidly determine which of the two test patterns was a member of the previously presented memory set. Subjects responded by indicating the position of the target pattern within the probe. The "four" key on the numeric keypad served as the "left" response; the "five" key served as the "right" response. A target was present within each probe set, and the position of the target within the probe was determined randomly on a trial-by-trial basis. Two dependent performance measures, reaction time and response accuracy, were collected. Each subject was encouraged to respond as rapidly as possible while maintaining an accuracy level of 90 percent or higher within each session.

In addition to the performance measures, workload ratings using the NASA-TLX (Hart and Staveland, 1988) were gathered from subjects at the completion of each even-numbered session. Standard TLX data collection procedures (which required a twenty-point rating on each of six dimensions) were completed by subjects. Ratings were obtained for both the memory set size two condition and the memory set size four condition. Half the subjects rated the workload associated with memory set size four first, while the remaining subjects rated the memory set size two workload first. At the completion of training, subjects also performed the TLX paired comparison procedure in which each dimension was rated for its contributions to workload within the visual/memory search task. Data from this paired comparison procedure were used during the data analysis phase to weight the ratings associated with each TLX dimension in order to derive an overall index of workload.

To investigate the interaction of memory set and session that had proven significant in the overall analysis, tests of the effects of memory set were conducted within the first and last sessions of training. These tests indicated that the effect of memory set was reliable in both the first ( $F(1,14) = 113.98$ ,  $p < .001$ ,  $MS_e = 6938.27$ ) and last ( $F(1,14) = 126.33$ ,  $p < .001$ ,  $MS_e = 812.84$ ) training sessions. Although the magnitudes of the  $F$  values from the respective analyses are approximately the same, error had been substantially reduced in the last training session relative to the first. Also, the effect of the memory set size had been considerably reduced in the last session relative to the first. This reduction is consistent with the data pattern illustrated in Figure 3-2, and constitutes the basis of the noted interaction.

To further characterize the reductions in the effect of memory set size on performance in each mapping condition, slopes of the functions depicted in Figure 3-2 were computed. Within the CM group, the slope of the Session 1 function was 138 ms, and the slope of the Session 20 function was 9 ms. In the VM group, however, the slope of the Session 1 function was 176 ms and was reduced to 104 ms by Session 20. Therefore, the CM group showed a 93 percent reduction in slope with training, as compared to a 41 percent reduction in the VM group. This type of CM/VM difference is consistent with automatic processing development in the CM group.

The significant interaction of mapping condition and memory set reported above is also consistent with the presence of a differential effect of memory set size within the CM and VM groups. Figure 3-3 depicts mean reaction time as a function of mapping condition and memory set. As expected, this figure shows that memory set had a more pronounced effect on VM versus CM performance. Subsequent to the significant mapping condition and memory set interaction, tests of simple main effects of memory set were conducted within the CM and VM groups. These analyses

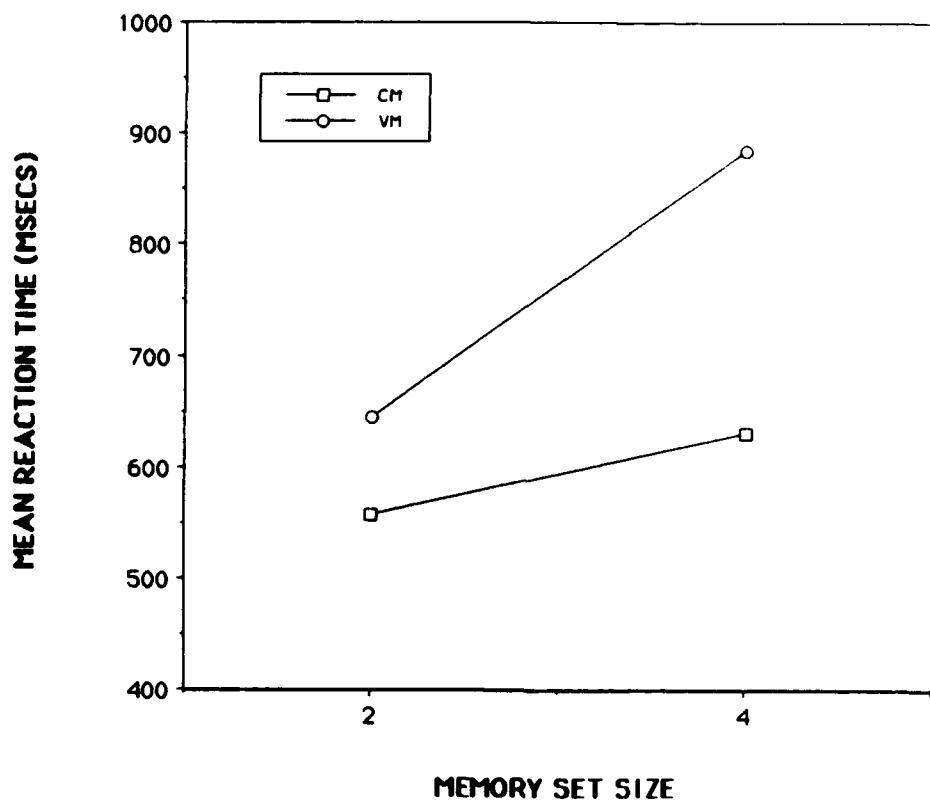


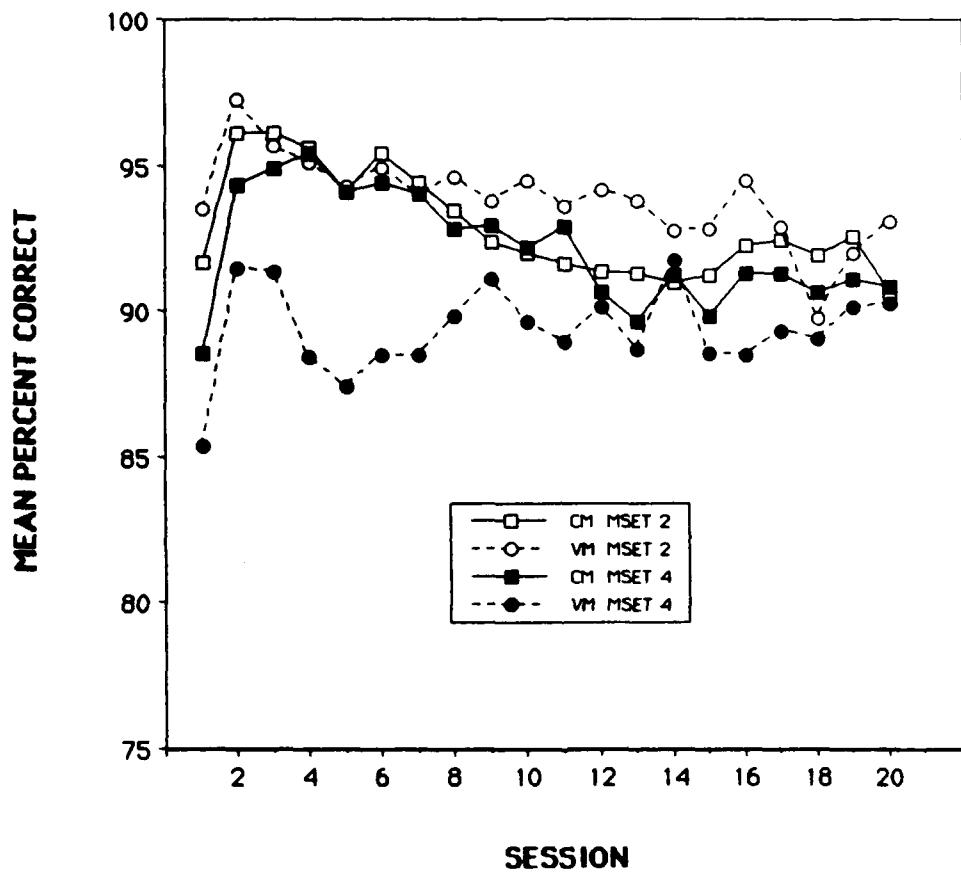
Figure 3-3. Mean Reaction Time as a Function of Mapping Condition and Memory Set Size.

indicated that the effect of memory set was significant within both the CM ( $F(1,14) = 19.52$ ,  $p < .005$ ,  $MS_e = 21875.10$ ) and VM ( $F(1,14) = 208.80$ ,  $p < .001$ ) conditions. Eta squared analyses of effect size indicated that the magnitude of the memory set size effect was greater in the VM condition (.937) than in the CM condition (.582). Therefore, memory set size exerted a smaller effect in the CM condition versus the VM condition; this result is consistent with the presence of some level of automatic processing within the CM group.

Therefore, the pattern of main effects and interactions in the reaction time analysis is consistent with some level of automatic processing development in the CM condition.

Accuracy of Responding. Figure 3-4 shows mean percent correct responses as a function of CM/VM group, memory set size, and training sessions. As seen in the figure, response accuracy was consistently high and generally improved in both groups across the initial sessions of training. While performance accuracy within the CM condition tended to be quite similar for memory set sizes of two and four patterns, the higher memory load tended to result in reduced accuracy within the VM condition.

A  $2 \times 2 \times 20$  ANOVA, comparable to that performed on the reaction time data, was conducted on the percent correct responses. This analysis demonstrated no main effect of the mapping condition ( $F(1,14) = 0.73$ ,  $p > .05$ ,  $MS_e = 186.81$ ), a significant main effect of memory set size ( $F(1,14) = 27.03$ ,  $p < .001$ ,  $MS_e = 40.31$ ), and a reliable effect of training sessions ( $F(19,266) = 4.36$ ,  $p < .001$ ,  $MS_e = 12.65$ ). Both the CM/VM and memory set ( $F(1,14) = 14.04$ ,  $p < .005$ ) and the CM/VM and training sessions ( $F(19,266) = 2.52$ ,  $p < .005$ ,  $MS_e = 4.75$ ) interactions were reliable. However, all other interactions proved to be nonsignificant.



**Figure 3-4.** Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Training Session.

Figure 3-5 shows mean percent correct as a function of memory set size and mapping condition in the first and last sessions of training. As illustrated in the figure, memory set tended to have a more pronounced effect on the performance of both the CM and VM groups during the first session of training than during the last. To investigate the significant interaction of memory set and training sessions, tests of the simple effects of memory set size were conducted within the Session 1 and Session 20 data. These analyses indicated that the effect of memory set was significant within Session 1 ( $F(1,14) = 22.66$ ,  $p < .001$ ,  $MS_e = 11.17$ ), but not Session 20 ( $F(1,14) = 1.463$ ,  $p > .05$ ,  $MS_e = 9.43$ ). Therefore, the noted interaction reflects the attenuation of the memory set size effect that occurred as a result of training.

Figure 3-6 illustrates mean percent correct as a function of mapping condition and memory set size. As shown in the figure, percent correct performance was very similar in both mapping conditions at memory set size two. However, VM performance showed a tendency to deteriorate at memory set size four, while CM performance tended to approximate those levels associated with memory set size two. The reliable CM/VM and memory set interaction was investigated through tests of the simple effects of memory set within the CM and VM conditions. These analyses showed that, while the effect of memory set was significant within the VM condition ( $F(1,14) = 40.01$ ,  $p < .001$ ,  $MS_e = 40.21$ ), it was not significant within the CM condition ( $F(1,14) = 1.05$ ,  $p > .05$ ). Therefore, the interaction reflects the reliable effect of memory set size on accuracy in the VM but not CM condition.

Thus, the pattern of results from the response accuracy analysis is consistent with the reaction time analysis and provides no basis to infer that a speed/accuracy tradeoff could have accounted for any of the noted patterns in the reaction time analysis. CM performance was unaffected by increases in memory

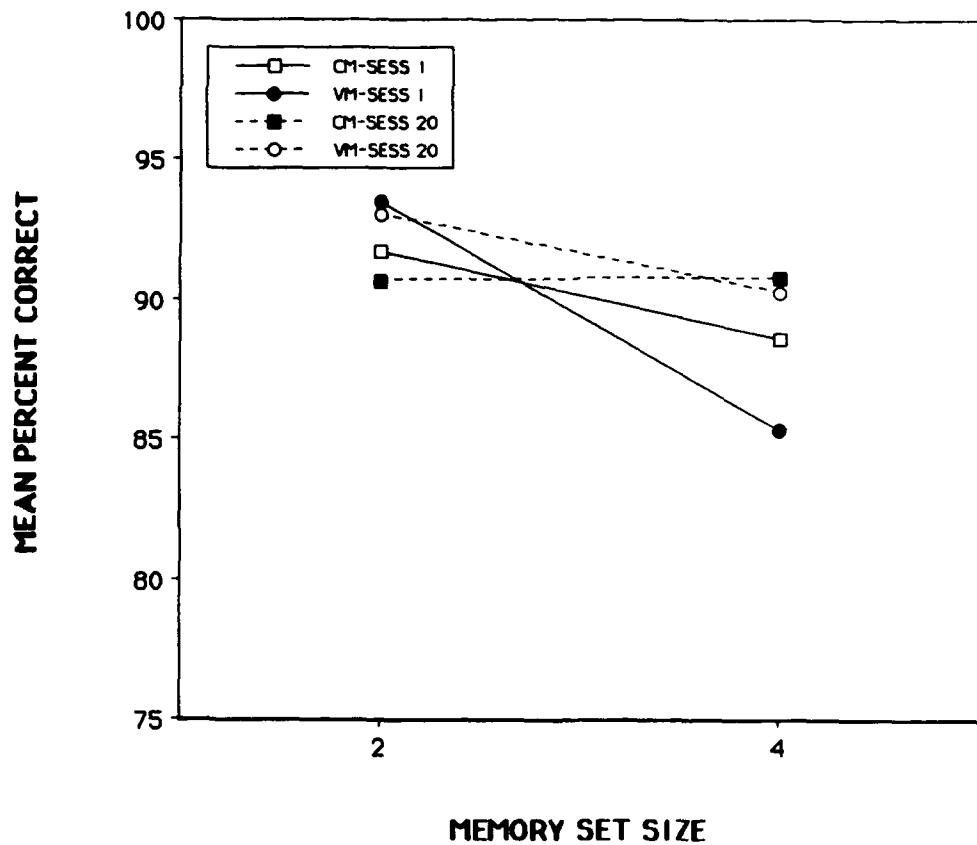


Figure 3-5. Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Training Session.

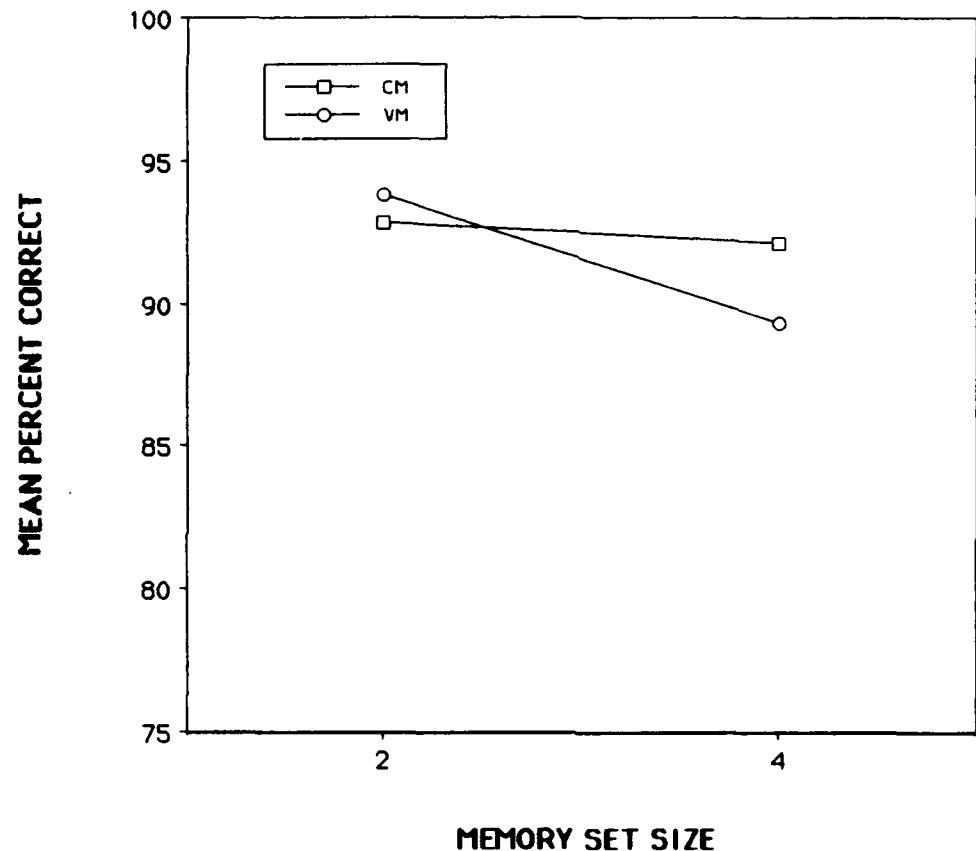
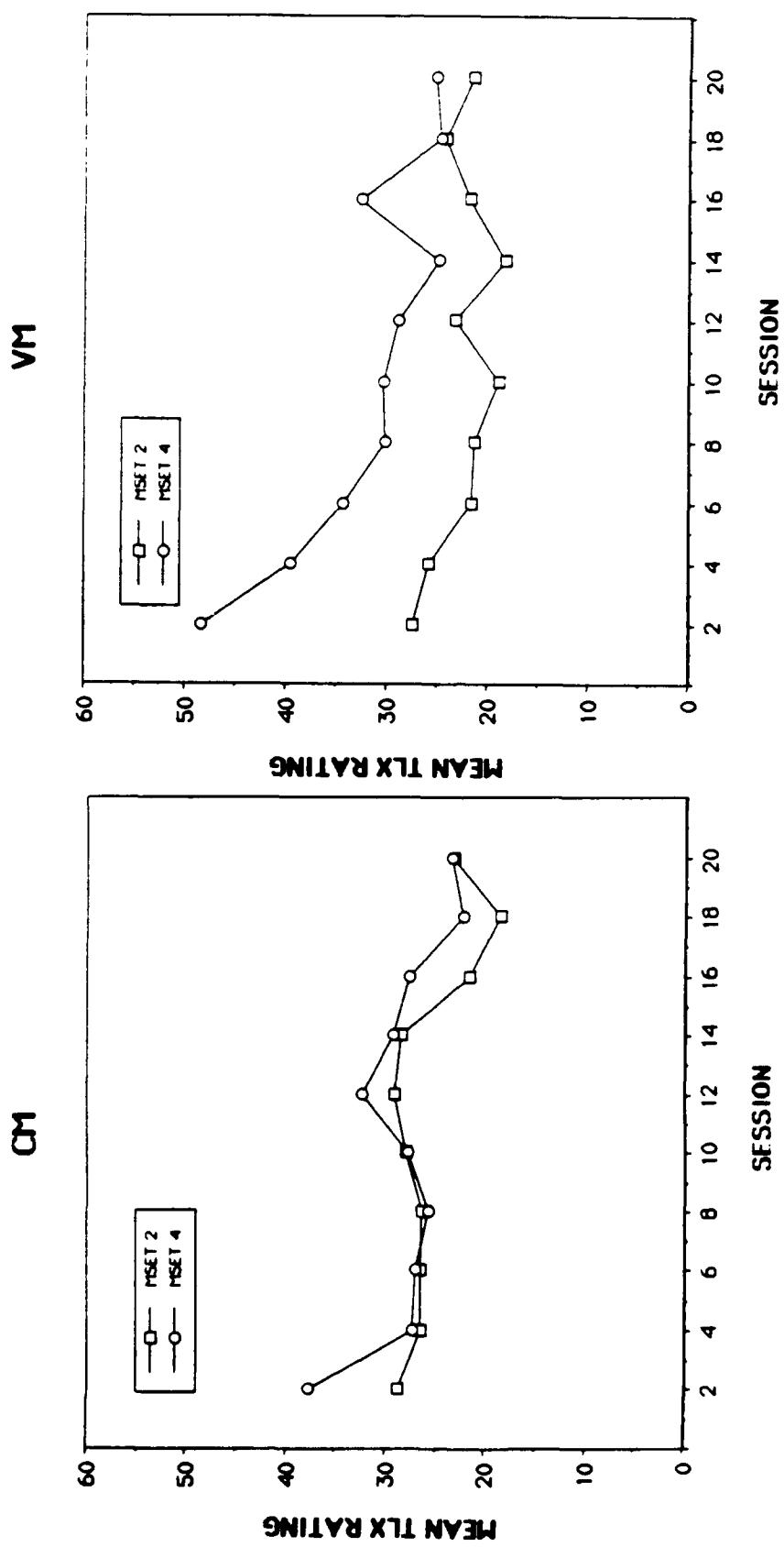


Figure 3-6. Mean Percent Correct as a Function of Mapping Condition and Memory Set Size.

set size, while VM performance deteriorated as a function of that manipulation.

NASA TLX Workload Ratings. Figure 3-7 depicts mean TLX workload ratings as a function of mapping condition, memory set size, and even-numbered training sessions. The ratings shown in Figure 3-7 are overall TLX workload ratings which represent the weighted combination of ratings on each of the six dimensions that are incorporated in the TLX procedure. As illustrated in the figure, the workload associated with task performance declined as a function of training in both mapping conditions, and VM workload ratings demonstrated a more marked difference as a function of memory set size than did CM ratings. There also appears to have been an attenuation of memory set effects in both mapping conditions as a function of training sessions.

A  $2 \times 2 \times 10$  ANOVA was performed on the data illustrated in Figure 3-7 to evaluate the effects of mapping condition (CM versus VM), memory set size (2 or 4), and even-numbered training sessions (2-20). As in the previous analyses, mapping condition was a between-subjects variable, while memory set size and training sessions were within-subjects variables. This ANOVA indicated that, although the main effect of mapping condition ( $F(1,14) = 0.001$ ,  $p > .05$ ,  $MS_e = 2388.03$ ) was not significant, the main effects of memory set size ( $F(1,14) = 20.03$ ,  $p < .005$ ,  $MS_e = 140.18$ ) and training sessions ( $F(9,126) = 3.03$ ,  $p < .005$ ,  $MS_e = 146.22$ ) were significant. The interactions of CM/VM and memory set ( $F(1,14) = 7.24$ ,  $p < .05$ ) and memory set and sessions ( $F(9,126) = 2.95$ ,  $p < .005$ ,  $MS_e = 39.52$ ) were also significant. Neither the CM/VM and sessions interaction nor the three-way interaction of CM/VM, memory set, and sessions was significant. The main effect of training sessions reflects the previously noted tendency for workload to decline in both mapping conditions as a function of training.



**Figure 3-7.** Mean TLX Workload Ratings as a Function of Mapping Condition, Memory Set Size, and Training Session.

Memory set size had a more marked effect on the workload associated with the VM condition as compared to the CM condition. To evaluate the significant CM/VM and memory set interaction, tests of the simple effects of memory set size were conducted within the CM and VM conditions. These analyses indicated that the effect of memory set size was significant within the VM condition ( $F(1,14) = 25.69$ ,  $p < .001$ ,  $MS_e = 140.18$ ) but not within the CM condition ( $F(1,14) = 1.59$ ,  $p > .05$ ). Therefore, as in the accuracy analyses, manipulations of memory set size had no reliable effect on the workload associated with performance within the CM condition, but did reliably affect the workload associated with task performance within the VM condition.

Figure 3-7 also demonstrated some attenuation of memory set size effects in both mapping conditions. To further investigate the significant memory set size and training sessions interaction, tests of the simple effects of memory set size were conducted within the Session 2 and 20 data. These analyses revealed that the effect of memory set size was reliable within Session 2 ( $F(1,14) = 12.71$ ,  $p < .001$ ,  $MS_e = 140.57$ ), but not within Session 20 ( $F(1,14) = 0.70$ ,  $p > .05$ ,  $MS_e = 42.76$ ). Therefore, one effect of the extensive training provided in this experiment was to eliminate the effect of memory set size on rated workload at the conclusion of training.

The workload analysis paralleled the results of the reaction time and accuracy analyses in demonstrating that the effect of memory set size was less pronounced in the CM than in the VM condition. As in the accuracy analysis, rated workload actually showed no effect of the memory set size manipulation within the CM condition but demonstrated a reliable effect of that manipulation within the VM condition. The workload associated with task performance declined in both the CM and VM conditions; this eliminated memory set size effects in both conditions at the conclusion of training.

## Discussion

The results of the current study extend previous results that demonstrated the development of automatic processing with static spatial pattern information within memory search tasks (e.g., Eggemeier et al., 1990, 1991) to the present combined visual/memory search paradigm. This is significant because visual/memory search functions constitute important components of many C<sup>2</sup> operator tasks. The present results indicate that automatic processing can be developed within such a paradigm with static spatial patterns intended to represent a major class of information processed by C<sup>2</sup> systems operators.

The current results not only indicate that automatic processing can be developed with such materials in a visual/memory search paradigm, but also demonstrate the superiority of CM performance to a hybrid VM condition of the type possibly encountered within operational systems. The present experiment utilized a variant of VM paradigms employed in earlier work with spatial pattern information (e.g., Eggemeier et al., 1990, 1991). In the noted previous work, memory search sets varied on a trial-by-trial basis within the VM condition. The present paradigm had target/distractor consistency within a ten-trial block in the VM condition, while the CM condition was characterized by both within and across-block consistency. The present results indicate that completely consistent mapping resulted in performance levels superior to those obtained in the hybrid VM condition, and that performance improved considerably within the latter condition as a function of training.

In addition to the performance advantages associated with the CM condition, the present results demonstrated that important workload advantages are associated with CM processing. CM processing was associated with no overall difference in the rated workload between memory set sizes two and four. However, overall VM ratings demonstrated that higher workload levels were

imposed by the memory set size four condition as compared with the memory set size two condition. Differences in rated workload associated with memory set size variations within a memory search paradigm have been previously demonstrated (Amell, Eggemeier, and Acton, 1987) with alphanumeric materials. The failure to find such differences in the CM condition is consistent with the development of automatic processing in that mapping condition. The current results also extend the work of Vidulich and Pandit (1986) who reported an attenuation of memory set size effects on rated workload under CM versus VM conditions within a semantic memory search paradigm.

#### Experiment 4

#### Acquisition of Automatic Processing Under Part-Task and Whole-Task Training Conditions with Complex Spatial Pattern Information in a Visual/Memory Search Task

#### Purpose

Experiment 3 demonstrated automatic processing development with static spatial pattern information in a visual/memory search paradigm. Experiment 4 employed static spatial pattern information within a visual/memory search task, but also included manipulations of display set size and memory set size in order to evaluate the effects of both variables on performance under CM and VM conditions. Air Force C<sup>2</sup> systems are characterized not only by variations in the memory load imposed on the operator, but by variations in the display load as well. Consequently, it was considered important to evaluate the joint effects of these two variables on CM and VM performance with static spatial pattern information of the type processed by C<sup>2</sup> operators.

A second objective of Experiment 4 was to evaluate the influence of whole-task versus part-task training under both CM

and VM conditions in a task containing complex static spatial patterns. Automatic processing development typically requires a large number of training trials. Thus, when evaluating the feasibility of automatic processing development within Air Force operator training programs, it is important to investigate techniques that can potentially facilitate the acquisition of automatic processing with information types processed in Air Force systems. Part-task training techniques constitute one such type of procedure that might facilitate the acquisition of automatic processing.

A variety of part-task training methods can be applied to skill acquisition. Wightman and Lintern (1985), for example, reviewed three such methods including segmentation, fractionization, and simplification. Segmentation involves breaking a complex task into sequential subcomponents that are trained separately and eventually recombined into the integrated whole task. Fractionization, a second part-task training procedure, can be applied in those instances that require the concurrent performance of two or more subcomponents. This approach to part-task training is designed to permit separate practice on subcomponents that would otherwise be trained concurrently. Simplification, the third part-task training technique, involves breaking a task into subcomponents that are simplified to facilitate their acquisition.

A simplification procedure variant was used in this experiment by breaking the entire stimulus pattern set into two subsets. Each subset contained only half the patterns in the entire stimulus set. Thus, this procedure permitted practice with a simpler stimulus set than the original; that is, fewer patterns had to be maintained in memory and discriminated by subjects during any given block of training trials. Fisk et al. (1991) applied a simplification procedure variant to automatic processing development in a semantic category search task. They reported no differences in acquisition between the part-task and

whole-task training methods. However, the present spatial pattern materials differ from the semantic categories used in the Fisk et al. (1991) research in that the latter were presumably familiar to subjects before entering the training procedure, while the former had to be learned by subjects during the initial training stages. Therefore, it was considered possible that a part-task training procedure which simplified stimulus retention and discrimination functions could facilitate performance with unfamiliar spatial pattern materials. Consequently, a second objective of the experiment was to investigate this possibility.

### Method

Subjects. Subjects were 32 University of Dayton students who were paid \$3.75/hour to participate. A \$1.25/hour bonus was also paid to those subjects who completed the experiment and attended each session on time. Subjects were randomly assigned to one of four training conditions. These conditions included: (a) consistently mapped/whole-task training (CM/WT), (b) consistently mapped/part-task training (CM/PT), (c) variably mapped/whole-task training (VM/WT), and (d) variably mapped/part task-training (VM/PT). There were eight subjects assigned to each training condition.

Apparatus. The experiment was controlled and the data were collected by Zenith Z-248 computers with extended keyboards. Stimuli were presented on Zenith ZCM-1490 high-resolution, thirteen-inch color monitors.

Stimulus Materials. A set of sixteen static spatial patterns was created by placing stars in selected cells of a 5 x 5 matrix. Patterns were designed to represent spatial pattern information processed by Air Force C<sup>2</sup> systems operators, and were selected to minimize overlap in their appearance. Each pattern consisted of five or six elements arranged as static

representations of various movement patterns associated with aircraft in Air Force C<sup>2</sup> systems.

Procedure. Subjects performed a visual/memory search task. On each trial, they were shown a memory set of two to four spatial patterns on the computer CRT screen. The patterns comprising the memory set were randomly selected from the target pattern set for the particular training condition for CM subjects, and from the entire stimulus set for the particular training condition for VM subjects. The memory set remained on the screen until the subject pressed the return key on the computer keyboard.

The memory set was replaced on the CRT screen with a test display containing either two or four patterns. Each test display included only one target and subtended a horizontal visual angle of approximately 6.9 degrees for a subject seated in the normal position with respect to the CRT screen. Each test display contained one target and either one or three distractor patterns arranged in a quadrant. The subject was instructed to rapidly determine which pattern was a member of the previously presented memory set. Subjects indicated the location of the target pattern by pressing a designated key on the numeric keyboard that corresponded to the quadrant in which the pattern appeared. The following keys were used to represent each quadrant: the "four" key represented the upper left quadrant, the "five" the upper right, the "one" the lower left, and the "two" the lower right. If the subject failed to respond within 3000 ms, the display was terminated and the system recorded a miss.

Memory set size varied randomly within blocks or sets of twenty trials, while display set size was blocked across sets of twenty trials. Blocking of the display set size variable followed an ABBA type of counterbalancing procedure within each training session. Half the subjects in each group were trained

first on a block of display set size two followed by two blocks of display set size four and a final block of display set size two (ABBA or 2,4,4,2). The remaining subjects in each group received the opposite order (BAAB or 4,2,2,4).

Two dependent measures, reaction time and response accuracy, were recorded. Subjects were encouraged to respond as rapidly as possible while maintaining a high level of accuracy.

Subjects received several types of feedback. After each trial, a message indicating whether the response was correct or incorrect appeared on the screen. The reaction time was given if the response was correct. At the end of each 20-trial block, the percent correct and mean reaction time over the twenty trials was shown. At the completion of each session, the percent correct and mean reaction time for the session were provided to the subject.

Subjects participated in ten days of training. A training day consisted of two one-hour sessions that included ten 20-trial blocks. Therefore, a total of 400 trials (20 blocks of 20 trials) took place each day.

Under the VM/WT training condition, targets and distractors were chosen from the complete set of sixteen patterns. No distinction was made between target and distractor patterns until they were randomly chosen for a specific trial. For the VM/PT condition, targets and distractors were chosen from one set of eight patterns during half the training trials, and from a second set of eight patterns on the other half of the trials. Pattern sets were practiced in blocks of 200 trials, and the order of set presentation followed the same type of ABBA counterbalancing scheme used with the display set size variable. The end result was that the whole target stimulus pattern set was trained; however, subjects in the VM/PT condition were required to work

only with half the entire stimulus set during any given 200-trial block.

Under CM conditions, certain patterns were designated as targets and others as distractors. In the CM/WT condition, one set of eight patterns served as targets for a particular subject, and the remaining patterns served as distractors. The CM/PT training group practiced only eight of the sixteen patterns in any given block of trials. In the CM/PT condition, four patterns served as targets for half the training trials for a particular subject, while four other patterns served as distractors on those trials. For the remaining trials, four other patterns served as targets, and the remaining four patterns served as distractors. Once again, the entire stimulus pattern set was practiced across training sessions, but subjects were required to practice only half the total stimulus set at any one time. As with the VM/PT group, target/distractor sets were practiced within the CM/PT group in 200-trial blocks; the order of presentation followed an ABBA counterbalancing procedure. Four different target/distractor sets, which included all sixteen patterns, were counterbalanced within both the CM/WT and CM/PT conditions such that each pattern served as a target and as a distractor an equal number of times across subjects.

Following every set of 800 training trials, subjects completed a 200-trial test session. These sessions tested all the groups under whole-task conditions that used the full stimulus set of sixteen patterns. Therefore, over the ten days of training, 4000 total acquisition trials, which included 3200 training trials and 800 test trials, were completed.

Design. Five independent variables were included in the design: (a) target/distractor mapping (CM versus VM), (b) training condition (part-task training, whole-task training), (c) display set size (2 or 4); (d) memory set size (2, 3, or 4), and (e) test sessions (1-4).

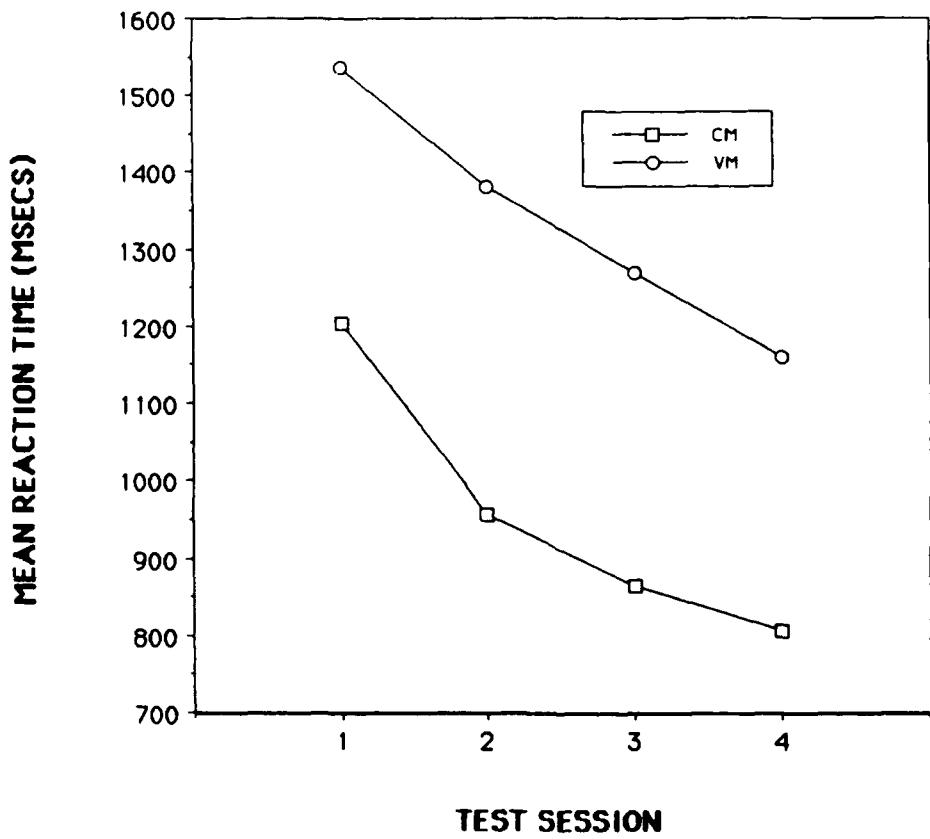
## Results

Mean Reaction Time Analyses. A  $2 \times 2 \times 3 \times 2 \times 4$  ANOVA was performed on the reaction time data to analyze the effects of mapping condition (CM versus VM), training type (whole-task, part-task training), memory set size (2, 3, or 4 patterns), display set size (2 or 4 patterns), and test session (1-4). Mapping condition and training type were between-subjects variables; the others were within-subjects variables.

The reaction time analysis indicated that the main effects of mapping condition ( $F(1,28) = 61.13$ ,  $p < .001$ ,  $MS_e = 452268.64$ ), memory set size ( $F(2,56) = 157.45$ ,  $p < .001$ ,  $MS_e = 17981.08$ ), display set size ( $F(1,28) = 855.80$ ,  $p < .001$ ,  $MS_e = 29357.16$ ), and test sessions ( $F(3,84) = 93.63$ ,  $p < .001$ ,  $MS_e = 57037.43$ ) were reliable.

The interactions of memory set size and display set size ( $F(2,56) = 16.11$ ,  $p < .001$ ), memory set size and mapping condition ( $F(2,56) = 52.25$ ,  $p < .001$ ), display set size and mapping condition ( $F(1,28) = 9.44$ ,  $p < .005$ ), and display set size and sessions ( $F(3,84) = 7.21$ ,  $p < .001$ ) were also significant. No effects involving training type (whole-task versus part-task training) or any other interactions were significant.

Figure 4-1 shows mean reaction time as a function of mapping condition and test sessions. The reaction times shown in the figure are based on correct responses. As illustrated in the figure, the CM condition was associated with lower mean reaction times than was the VM condition across test sessions. Clearly, performance improved as a function of test session in both mapping conditions. The main effects of mapping condition and test session reflect these trends.

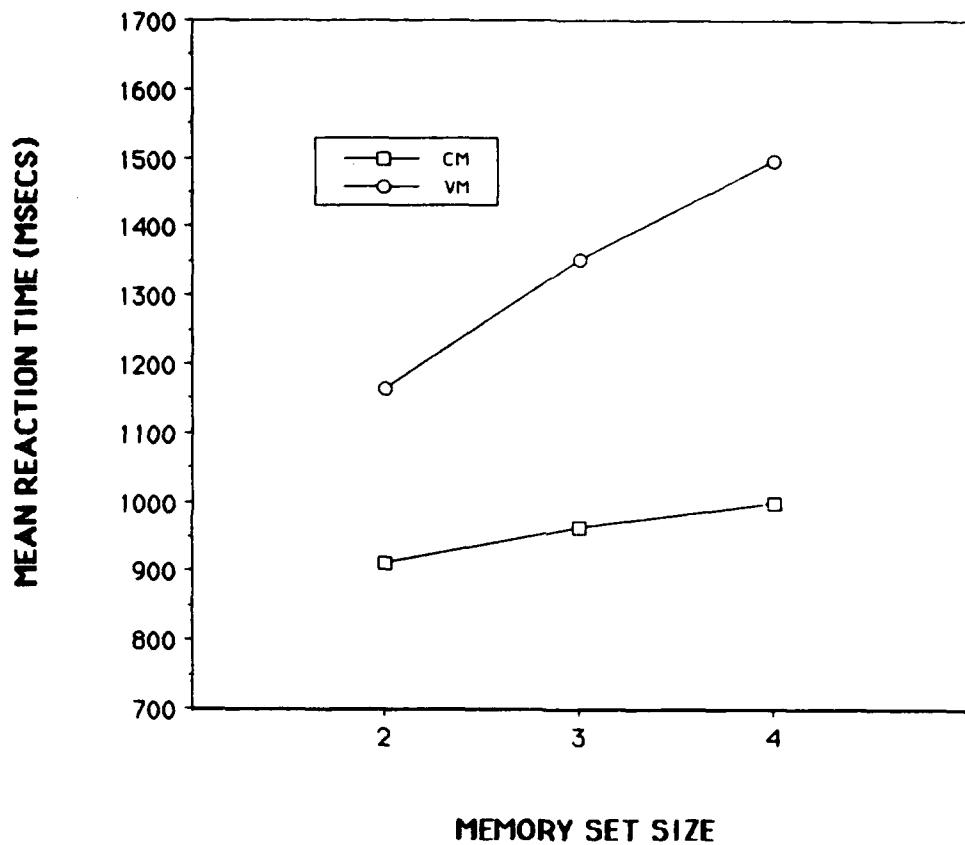


**Figure 4-1.** Mean Reaction Time as a Function of Mapping Condition and Test Session.

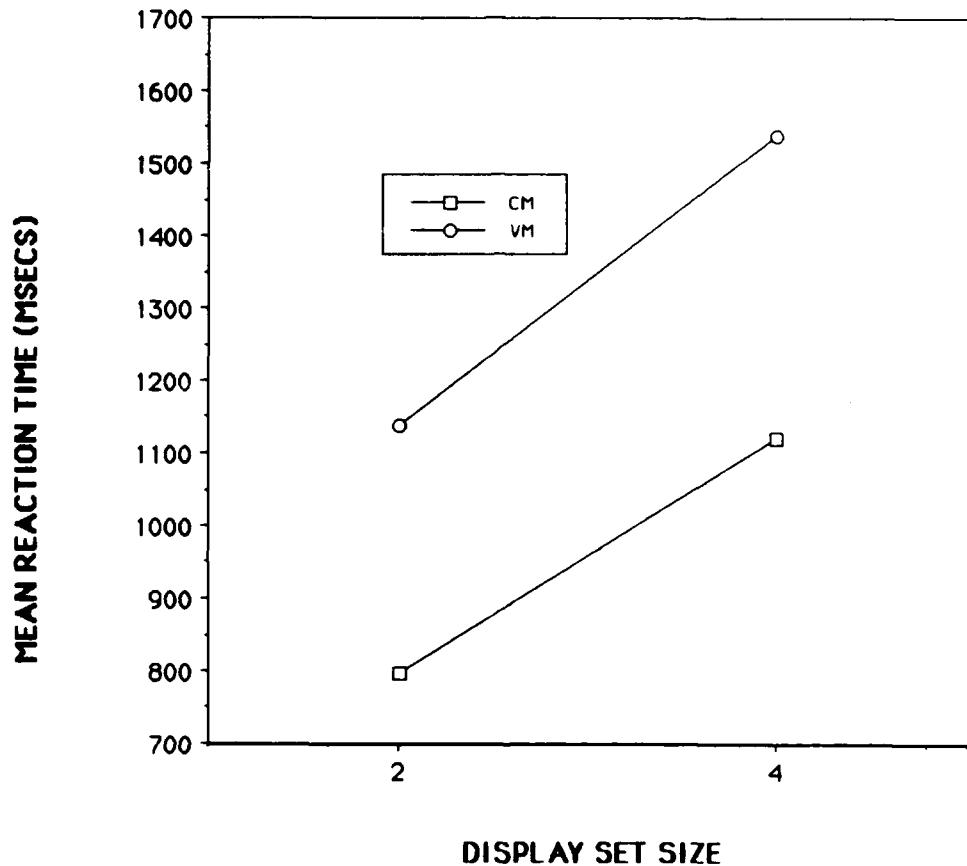
Figure 4-2 depicts mean reaction time as a function of mapping condition and memory set size. As shown in the figure, mean reaction time generally increased with increased memory set size, but the increase was less pronounced in the CM mapping condition than in the VM mapping condition. This attenuation of memory set size effects in the CM condition relative to the VM condition is reflected in the slopes of the reaction time functions depicted in Figure 4-2. For the CM condition, the slope of the function was 44.3 ms, while in the VM condition, the comparable slope was 165.2 ms.

To further investigate the reliable mapping condition and memory set interaction, tests of memory set size main effects were performed within the CM and VM conditions. These analyses revealed that memory set size effects were significant in both the CM ( $F(2,56) = 14.17$ ,  $p < .001$ ,  $MS_e = 17981.08$ ) and VM ( $F(2,56) = 195.54$ ,  $p < .001$ ) conditions. Tukey HSD post-hoc tests showed that in the CM condition, memory set size two differed reliably ( $p < .05$ ) from memory set sizes three and four. Memory set sizes three and four did not differ significantly. In contrast to the CM results, all memory set sizes differed reliably within the VM condition. This attenuation of memory set size effects in the CM versus VM condition is consistent with some level of automatic processing development within the CM condition.

Figure 4-3 shows the effect of display set size on mean reaction time in both the CM and VM conditions. As reflected in the figure, the main effect of display set size is attributable to higher reaction times in the display set size four versus the display set size two condition. The figure also illustrates that the display set size effect was somewhat more pronounced in the VM relative to the CM condition; this difference is reflected in the reliable interaction of mapping condition and display set size. The slopes of the functions depicted in the figure are 200 ms and 162 ms in the VM and CM conditions, respectively. Tests



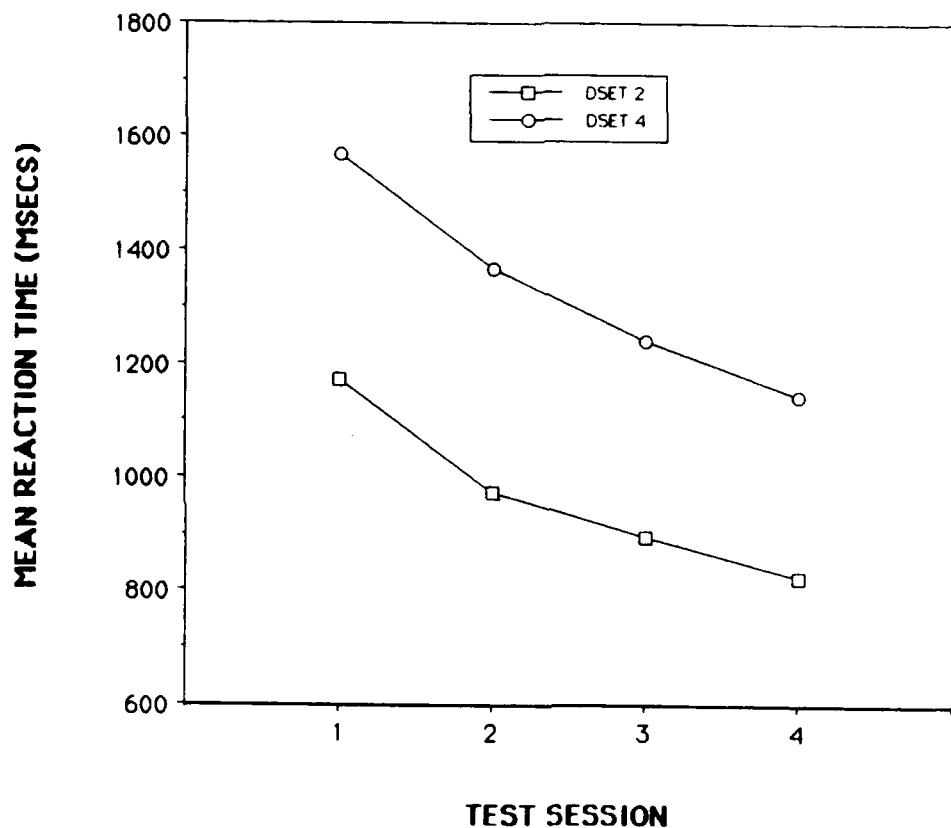
**Figure 4-2.** Mean Reaction Time as a Function of Mapping Condition and Memory Set Size.



**Figure 4-3.** Mean Reaction Time as a Function of Mapping Condition and Display Set Size.

of the main effect of display set size were conducted within the CM and VM conditions to investigate the reliable mapping condition and display set size interaction. These analyses indicated that the display set effect was reliable in both the CM ( $F(1,28) = 342.75, p < .001, MS_e = 29375.16$ ) and VM ( $F(1,28) = 522.49, p < .001$ ) conditions. Although both effects were reliable, Eta squared analyses indicated that the effect within the VM condition (.949) was of somewhat greater magnitude than that within the CM condition (.924). Therefore, as with the effect of memory set size on reaction time performance, the CM condition resulted in an attenuation of the display set size effect relative to the VM condition. This attenuation, although more modest than that associated with the memory set size effect, is consistent with some level of automatic processing development in the CM condition.

The display set size and sessions interaction also proved to be significant. The basis of this interaction is illustrated in Figure 4-4, which shows mean reaction time as a function of display set size and test sessions. As demonstrated in the figure, the effect of display set size tended to decrease with successive test sessions. Tests of the simple effect of display set size were conducted at each test session to investigate the reliable display set size and sessions interaction. These analyses revealed significant effects of display set size during Session 1 ( $F(1,28) = 494.88, p < .001, MS_e = 15137.31$ ), Session 2 ( $F(1,28) = 499.04, p < .001, MS_e = 14776.33$ ), Session 3 ( $F(1,28) = 411.64, p < .001, MS_e = 13665.55$ ), and Session 4 ( $F(1,28) = 328.82, p < .001, MS_e = 14726.00$ ). Eta squared analyses of effect size showed that the display set size effect was comparable in Sessions 1 (.946) and 2 (.947), but showed some decline in Sessions 3 (.936) and 4 (.922). As indicated by these analyses, the magnitude of the display set size effect tended to show a decrease during the last test sessions; this is the basis of the noted interaction.



**Figure 4-4.** Mean Reaction Time as a Function of Display Set Size and Test Session.

The previously described ANOVA also demonstrated a reliable interaction between memory set size and display set size. Figure 4-5 shows the basis of this interaction and illustrates mean reaction time as a function of the two variables. As seen in the figure, memory set size effects were more pronounced at display set size four than at display set size two. To further investigate the reliable interaction, tests of memory set size effects were conducted within the display set size two and size four conditions. These analyses indicated that memory set size effects were reliable in both the display set size two ( $F(2,56) = 109.22, p < .001, MS_e = 7901.80$ ) and display set size four ( $F(2,56) = 112.99, p < .001, MS_e = 18639.55$ ) conditions. Eta squared analyses indicated that the memory set size effect was greater under the display set size four condition (.801) than the display set size two condition (.796). Thus, the interaction reflects the fact that the effect of memory set was more pronounced under the display set size four than under the display set size two condition.

The reaction time ANOVA had not revealed a main effect or any reliable interactions involving whole- versus part-task training. Figure 4-6 shows the mean reaction time as a function of CM/VM mapping condition and training type (WT or PT). As illustrated in the figure, there was very little difference between whole- and part-task training conditions for either the CM or VM conditions.

Accuracy Analyses. In addition to mean reaction time, the percent correct response data were analyzed. A  $2 \times 2 \times 3 \times 2 \times 4$  ANOVA, comparable to the reaction time analysis, was performed on the percent correct data to assess the effects of mapping condition (CM versus VM), training type (whole- versus part-task training), memory set size (2, 3, or 4 patterns), display set size (2 or 4 patterns) and test session (1-4). This analysis indicated that the main effects of mapping condition

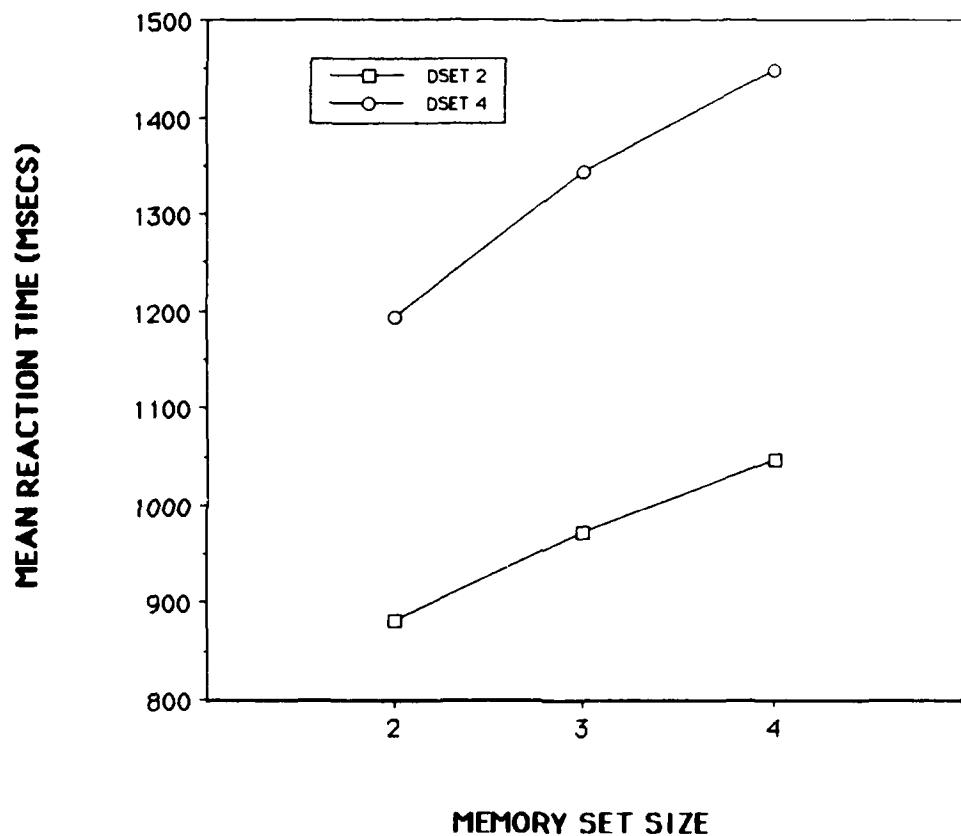


Figure 4-5. Mean Reaction Time as a Function of Memory Set Size and Display Set Size.

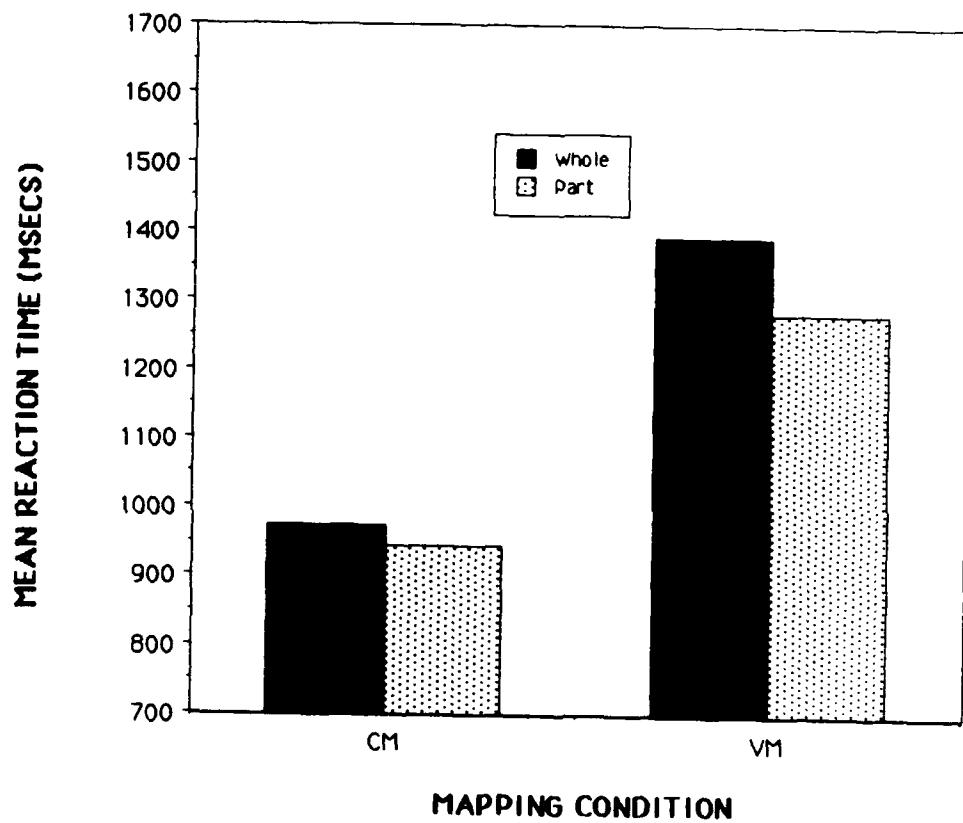


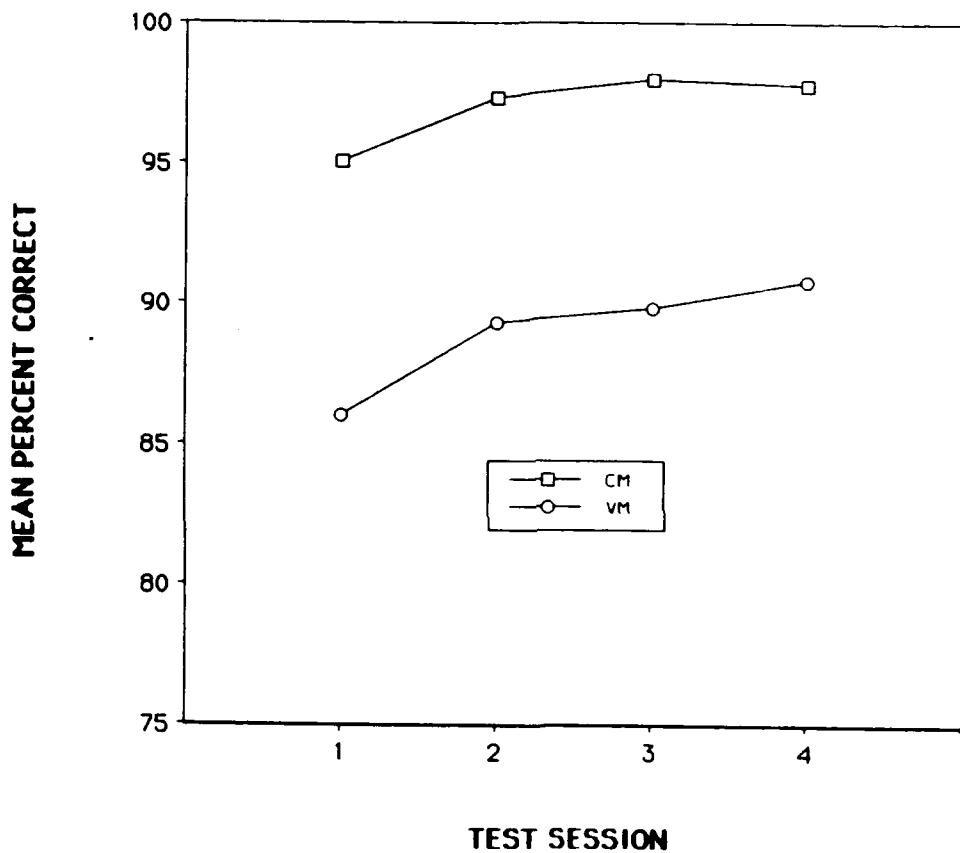
Figure 4-6. Mean Reaction Time as a Function of Mapping Condition and Training Type.

( $F(1,28) = 19.76$ ,  $p < .001$ ,  $MS_e = 628.84$ ), memory set size ( $F(2,56) = 35.36$ ,  $p < .001$ ,  $MS_e = 66.04$ ), display set size ( $F(1,28) = 60.64$ ,  $p < .001$ ,  $MS_e = 77.60$ ), and test sessions ( $F(3,84) = 9.02$ ,  $p < .001$ ,  $MS_e = 61.81$ ) were significant.

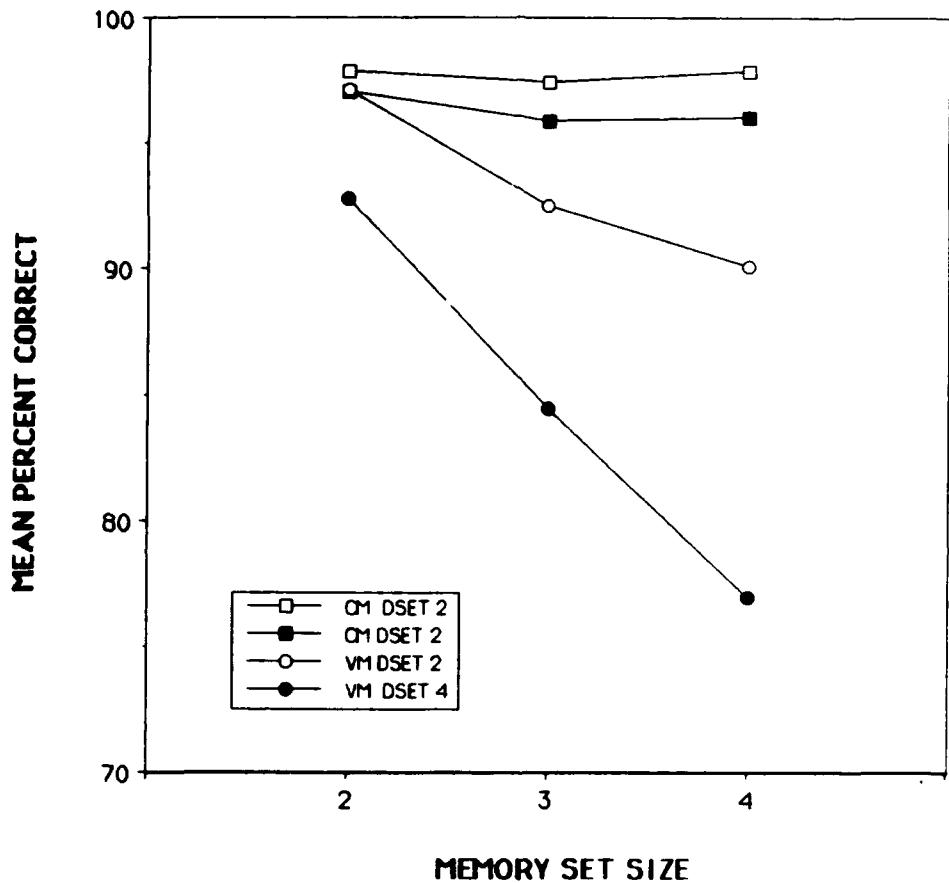
The interactions of memory set size and display set size ( $F(2,56) = 21.17$ ,  $p < .001$ ,  $MS_e = 18.60$ ), memory set size and mapping condition ( $F(2,56) = 28.83$ ,  $p < .001$ ), display set size and mapping condition ( $F(1,28) = 31.36$ ,  $p < .001$ ), display set size and sessions ( $F(3,84) = 5.31$ ,  $p < .01$ ), and memory set size and training type (WT/PT) ( $F(2,56) = 3.17$ ,  $p < 0.05$ ) were significant. The three-way interactions of mapping condition, memory set size, and display set size ( $F(2,56) = 13.32$ ,  $p < .001$ ), and mapping condition, memory set size, and training type ( $F(2,56) = 4.81$ ,  $p < .05$ ) were also reliable.

Figure 4-7 illustrates the effects of mapping condition and test sessions on mean percent correct responses. As depicted in the figure, the percent correct responses associated with the CM condition were consistently higher than those associated with the VM condition. Percent correct responses also tended to increase as a function of test session; this trend is particularly marked between Sessions 1 and 2. The superiority of the CM condition relative to the VM condition and the trend for increased accuracy as sessions progressed are reflected in the previously noted main effects of mapping condition and sessions, respectively.

The percent correct ANOVA also indicated that the main effect of memory set size; the two-way interactions of mapping condition and memory set size, mapping condition and display set size, memory set and display set size; and the three-way interaction of mapping condition, memory set, and display set were significant. Figure 4-8 depicts mean percent correct as a function of mapping condition, display set size, and memory set size. As indicated by the figure, both memory set and display set had a greater impact on VM performance than CM performance.



**Figure 4-7.** Mean Percent Correct as a Function of Mapping Condition and Test Session.



**Figure 4-8.** Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Display Set Size.

Within the VM condition, increases in both memory set and display set were associated with reductions in the accuracy of performance, while these trends were much less marked in the CM condition.

To investigate the three-way interaction between mapping condition, memory set, and display set, an analysis of memory set and display set was conducted within the CM and VM conditions. Within the CM condition, the effect of memory set ( $F(2,56) = 0.34$ ,  $p > .05$ ,  $MS_e = 66.04$ ), display set ( $F(1,28) = 2.39$ ,  $p > .05$ ,  $MS_e = 77.60$ ), and the memory set and display set interaction ( $F(2,56) = 0.49$ ,  $p > .05$ ,  $MS_e = 18.60$ ) all proved nonsignificant. Within the VM condition, however, the effect of memory set ( $F(2,56) = 64.06$ ,  $p < .001$ ), display set ( $F(1,28) = 89.60$ ,  $p < .001$ ), and the memory set and display set interaction ( $F(2,56) = 34.00$ ,  $p < .001$ ) were significant.

As seen in Figure 4-8, the effects of memory set size appear to be more pronounced in the display set size four condition versus the display set size two condition. The reliable interaction between memory set and display set within the VM condition was examined further by tests of the memory set size effect at each display set size. These analyses revealed that the effect of memory set was reliable in both the display set size two ( $F(2,56) = 32.09$ ,  $p < .001$ ,  $MS_e = 25.32$ ) and the display set size four ( $F(2,56) = 68.05$ ,  $p < .001$ ,  $MS_e = 59.31$ ) conditions. Eta squared analyses of effect size indicated that the magnitude of the memory set size effect was greater at display set size four (.708) than at display set size two (.534). Therefore, the results of these analyses indicate that, within the VM condition, display set size and memory set size interacted to determine percent correct performance; within the CM condition, neither variable had an effect on performance.

The interaction between sessions and display set size also proved reliable in the overall ANOVA. Figure 4-9 illustrates mean percent correct responses as a function of display set size and test sessions. As training progressed, accuracy increased and the display set size effect was attenuated. The effects of display set size were analyzed at each test session. The results revealed reliable effects of display set size at Session 1 ( $F(1,28) = 58.28$ ,  $p < .001$ ,  $MSe = 41.69$ ), Session 2 ( $F(1,28) = 63.77$ ,  $p < .001$ ,  $MSe = 16.69$ ), Session 3 ( $F(1,28) = 17.99$ ,  $p < .001$ ,  $MSe = 57.32$ ), and Session 4 ( $F(1,28) = 18.51$ ,  $p < .001$ ,  $MSe = 29.0$ ). Eta squared analyses of effect size indicated that the magnitude of the display set size effect remained approximately stable across Session 1 (.675) and Session 2 (.695), but declined in Session 3 (.220) and Session 4 (.336). As demonstrated by these analyses, the magnitude of the display set size effect decreased during the last two test sessions relative to the first two sessions; this decrease is reflected in the noted interaction.

As in the reaction time analysis, the overall ANOVA for the percent correct data did not reveal a significant main effect of whole- versus part-task training. However, both the memory set and training type interaction and the three-way interaction between mapping condition, memory set, and training type proved to be significant. Figure 4-10 shows mean percent correct as a function of mapping condition, memory set size, and training type. As seen in the figure, neither training type nor memory set markedly affected performance within the CM group, but both variables influenced performance within the VM group. In the latter group, whole-task training was associated with lower accuracies than part-task training, and increases in memory set size were associated with decreases in the accuracy of performance.

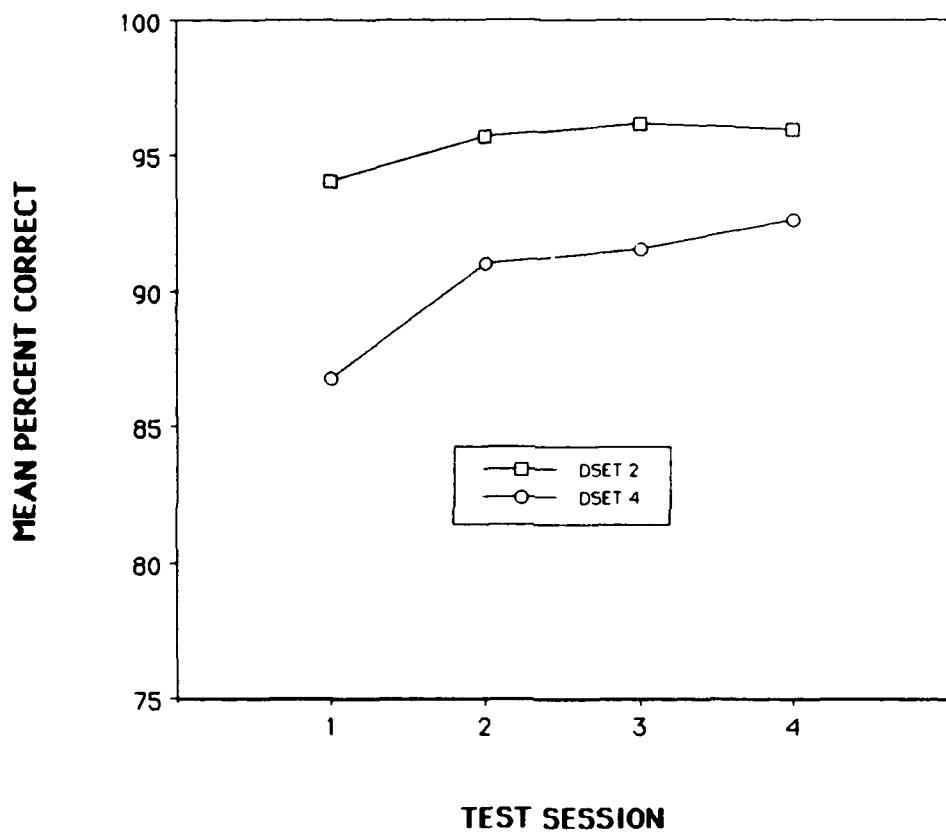


Figure 4-9. Mean Percent Correct as a Function of Display Set Size and Test Session.

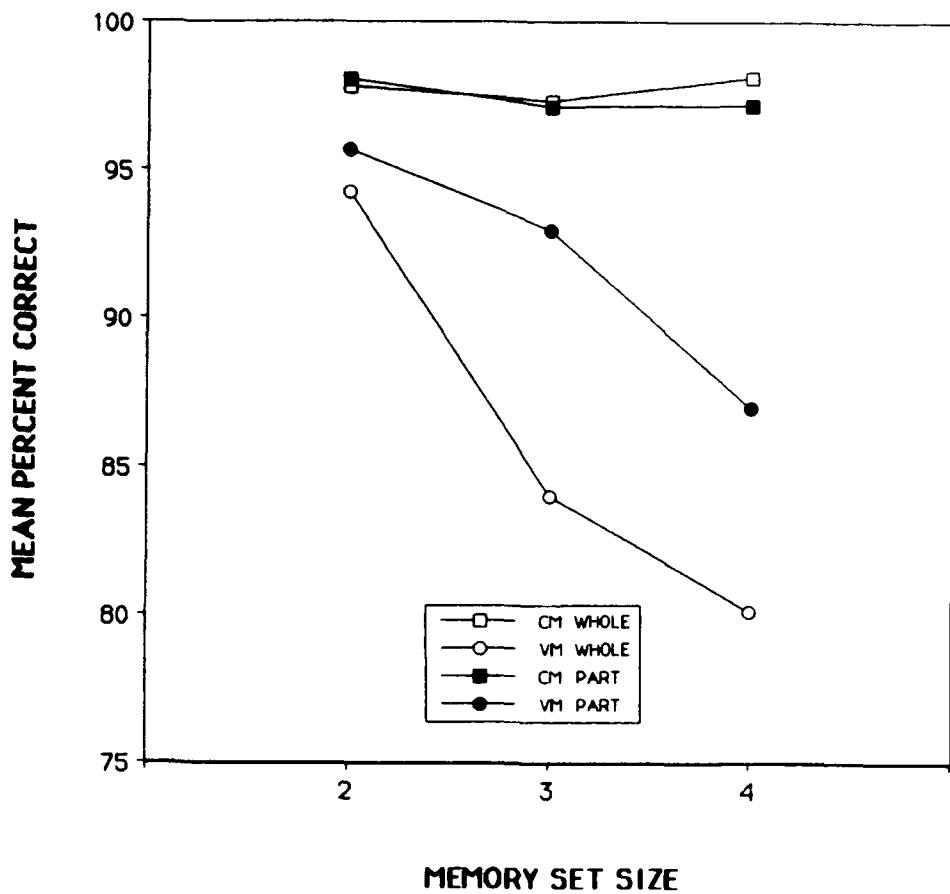


Figure 4-10. Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Training Type.

To investigate the reliable three-way interaction, an analysis of training type and memory set was conducted within the CM and VM conditions. Within the CM condition, there was no effect of training type ( $F(1,28) = 0.32$ ,  $p > .05$ ,  $MS_e = 628.84$ ), no effect of memory set ( $F(2,56) = 0.34$ ,  $p > .05$ ,  $MS_e = 66.04$ ), and no reliable training type and memory set interaction ( $F(2,56) = 0.33$ ,  $p > .05$ ). However, within the VM condition, the effect of training type ( $F(1,28) = 5.07$ ,  $p < .05$ ), memory set size ( $F(2,56) = 63.85$ ,  $p < .001$ ), and the training type and memory set interaction ( $F(2,56) = 7.38$ ,  $p < .01$ ) proved to be reliable.

Tests of the memory set size effect at each level of the training type variable were conducted within the VM condition. The results showed that the memory set size effect was reliable in both the part-task ( $F(2,56) = 19.30$ ,  $p < .001$ ,  $MS_e = 66.04$ ) and whole-task ( $F(2,56) = 51.93$ ,  $p < .001$ ) conditions. Eta squared analyses revealed that, as expected from the pattern of data in Figure 4-10, the magnitude of the memory set effect was greater within the whole-task (.650) than the part-task (.408) training condition.

The results of the percent correct analysis paralleled those of the reaction time analysis and demonstrated superior performance within the CM versus VM condition. As was the case in the reaction time analysis, display set size and memory set size had a greater impact on performance within the VM condition than the CM condition. In fact, neither variable reliably affected performance accuracy within the CM condition. Thus, the results of the accuracy analysis are consistent with some level of automatic processing development within the CM condition and provide no evidence of any speed/accuracy tradeoff that could affect interpretation of the reaction time data.

Unlike the reaction time analysis, the percent correct data did show an effect of whole-task versus part-task training. This effect was limited to the VM condition and reflected a more

pronounced effect of memory set size under whole-task versus part-task training conditions.

### Discussion

The overall pattern of results from this experiment are consistent with some level of automatic processing development within the CM condition. These results extend those of Experiment 3 to the conditions employed in the current experiment. In the present experiment, CM performance was superior to VM performance across test sessions and was less affected by manipulations of both the memory set and display set variables.

Attenuation of the reaction time memory set size effect in the CM relative to the VM condition was more marked than the comparable attenuation of the display set size effect. These data suggest that, with the search display conditions and amount of training used here, the level of automatic processing established had a less pronounced influence on display set size reaction time effects than on memory set size effects. This latter finding is of potential importance to eventual applications of automatic processing to C<sup>2</sup> systems because it suggests that display set size reaction time effects might not be attenuated to the same degree as memory set size effects under equivalent levels of training in CM versus VM conditions. Attenuation of display set size effects could prove to be quite important within C<sup>2</sup> systems; thus it should be investigated under more extended training and in a variety of search display conditions in future work.

The variant of whole-task versus part-task training used here failed to exert a substantial influence on the performance levels achieved, particularly within the CM condition. The only advantage of part-task training was found within the VM condition where it was associated with a reduction in the effect of memory

set size on performance accuracy. Therefore, any benefits associated with the reduced stimulus pattern retention and discrimination requirements under part-task training conditions were sufficient only to facilitate performance under the mapping condition in which the role of patterns as targets or distractors varied from trial to trial. The CM results are consistent with those obtained by Fisk et al. (1991), who reported no effect of part-task training on acquisition performance with semantic category information in a different variant of a visual/memory search task. The present results provide no basis to recommend the part-task training technique used here as a means of facilitating automatic processing development with spatial pattern information in a visual/memory search task.

#### Summary and General Discussion

The experiments described in this section support the capability of subjects to develop automatic processing with two major classes of information processed by C<sup>2</sup> systems operators. The first two experiments provide evidence of automatic processing in a complex alphanumeric, rule-based task within memory search and visual/memory search paradigms. The memory search paradigm employed in Experiment 1 incorporated several levels of consistency and, following training, performance levels directly reflected the degree of consistency within the task.

Experiment 2 extended the results of the first experiment to rule-based processing in a visual/memory search task. In addition to providing performance data that were consistent with the development of automatic processing under CM conditions in the visual/memory search paradigm, Experiment 2 demonstrated that the levels of subjective workload associated with rule-based task performance were lower under CM conditions than VM conditions. Reductions in the workload imposed by task performance are an aspect of automatic processing that could prove extremely important in applications to C<sup>2</sup> systems. The results of the

second experiment confirmed the expectation that performance of the rule-based task under automatic processing conditions would be associated with lower workload than under controlled processing conditions.

Experiments 3 and 4 provided evidence of automatic processing development with static spatial pattern information representative of a second major class of information processed by C<sup>2</sup> systems operators. Both experiments, conducted within a visual/memory search paradigm, extended earlier work (Eggemeier et al., 1990, 1991) that had demonstrated the capability of subjects to develop automatic processing with static spatial pattern information in a memory search task.

Experiment 3 evaluated the subjective workload associated with CM and VM conditions within the visual/memory search paradigm and demonstrated that variations in memory set size reliably affected the workload associated with VM but not CM performance. This lack of workload variance with increased task demand constitutes an additional characteristic of automatic processing which could represent an important advantage of such processing within C<sup>2</sup> systems that can impose heavy processing demands on such operators.

Finally, Experiment 4 investigated the effects of variations in both display set size and memory set size on performance under CM and VM conditions within a visual/memory search task. The results showed that the attenuation of display set size effects under CM relative to VM conditions was less pronounced than the attenuation of memory set size effects. This result is of potential importance to automatic processing applications within C<sup>2</sup> systems because such systems can impose high levels of display load on the operator. The present results suggest that more extensive evaluation of the attenuation of display set size effects under CM versus VM conditions represents an important issue for future research. Experiment 4 also evaluated the

effects of part-task versus whole-task training on automatic processing development with static spatial pattern information. There were no performance differences between part- and whole-task training under CM conditions. Therefore, the current results do not support use of the present part-task training technique as a means of facilitating automatic processing development with spatial pattern information in a visual/memory search task.

The combined results of these experiments indicate that automatic processing can be developed with spatial pattern and complex alphanumeric information within two search tasks of the type performed by C<sup>2</sup> systems operators. The data not only demonstrate performance (i.e., speed, accuracy) advantages associated with automatic processing, but also indicate that automatic processing results in reduced levels of workload under the conditions studied.

### III. TRANSFER OF AUTOMATIC PROCESSING IN TASKS REQUIRING THE PROCESSING OF SPATIAL PATTERN OR ALPHANUMERIC INFORMATION

Additional important issues that pertain to the application of automatic processing to C<sup>2</sup> operator performance concern the transfer of automatic processing that can be expected with the information processed by these operators. Data concerning the conditions and limits of automatic component transfer are very important for the design of training programs intended to support automatic processing development within consistent task components.

One issue relevant to the rule-based search task reported in the previous section concerns transfer of alphanumeric rules to untrained exemplars. Because automatic processing development can require thousands of acquisition trials, significant time

savings could be realized in training programs if only a limited subset of rule exemplars had to be trained. This approach could be undertaken if positive transfer of trained rules to untrained exemplars could be established.

Several previous experiments (e.g., Hale and Eggemeier, 1990; Hassoun and Eggemeier, 1988; Schneider and Fisk, 1984) have demonstrated automatic processing transfer to untrained exemplars of trained semantic categories within memory and visual/memory search paradigms. Rule-based search functions play a critical role within C<sup>2</sup> systems. Therefore, it is important to investigate extensions of this type of transfer to untrained exemplars of the complex alphanumeric rules investigated in Experiments 1 and 2 in the present series.

A second transfer-of-training issue, critical to the design of training programs to support automatic processing development in subcomponents of C<sup>2</sup> operator tasks, concerns the effect of rotating previously trained spatial patterns on performance under CM and VM conditions. C<sup>2</sup> systems can require the detection and processing of critical patterns in a variety of spatial rotations. Therefore, it is important that rotation effects be investigated with the type of complex spatial patterns investigated in Experiments 3 and 4 in this series.

Previous work (Eberts and Schneider, 1986) on the rotation of spatial patterns under CM conditions indicated that such rotations reduced performance levels with previously trained CM patterns to the same levels exhibited by VM patterns. This has important implications for the design of training programs. It suggests that such programs should be designed to permit practice with critical patterns under a variety of rotations in order to preserve the advantages of CM processing. Thus, additional investigations of the type represented in the Eberts and Schneider (1986) experiment are essential to the specification of

training programs designed to permit automatic processing of spatial pattern information in C<sup>2</sup> systems.

A third important transfer of training issue concerns possible task recombinations in which originally trained target/distractors are incorporated into a new task. Such a task could require that targets/distractors serve either the same or different roles as under original training, and it is important to determine the performance levels associated with various task recombinations that might be encountered within operational systems. Previous research (e.g., Dumais, 1979; Fisk et al., 1990, 1991; Shiffrin and Schneider, 1977) has addressed the recombination issue in tasks with a visual search component with semantic-based, symbolic, and alphanumeric materials. However, it is important to extend this earlier work to memory search functions that involve the processing of spatial pattern information of the type found in some C<sup>2</sup> systems.

#### Overview of Present Studies

Experiments 5 and 6 examined the transfer of training associated with untrained exemplars of the complex alphanumeric rules investigated in Experiments 1 and 2. Experiment 5 investigated this type of transfer within a memory search paradigm under the three levels of consistency (CM, VM/CM, and VM) incorporated into the rule-based task studied in Experiment 1. Experiment 6 examined rule-based transfer in the visual/memory search task that had been studied in Experiment 2. Experiment 7 addressed the issue of transfer under conditions of pattern rotation within the visual/memory search task investigated in Experiment 4. Finally, Experiment 8 investigated the transfer of training that would result from various task recombinations in a memory search task that required spatial pattern information processing.

Experiment 5  
Transfer of Training with Complex Alphanumeric Materials  
in a Rule-Based Search Task

Purpose

The purpose of this experiment was to investigate the transfer of CM and VM training to untrained exemplars of previously trained rules in the complex alphanumeric memory search task investigated in Experiment 1. The issue of transfer from a limited subset of the exemplars/non-exemplars associated with a particular rule has significant practical implications for the design of training programs. It is also of theoretical importance because positive transfer to untrained exemplars would indicate that the learning that had occurred during training had been at the rule level rather than the individual exemplar level. Therefore, this experiment was conducted to determine the resulting performance level when subjects trained under CM, VM/CM, or VM conditions in the complex alphanumeric rule task of Experiment 1 were transferred to untrained exemplars of trained rules. A control condition in which subjects were transferred to a task that involved the processing of completely different rules and exemplar sets was also included.

A number of investigators (e.g., Hale and Eggemeier, 1990; Hassoun and Eggemeier, 1988; Schneider and Fisk, 1984) have demonstrated positive transfer of trained semantic categories to untrained exemplars under CM conditions. Thus, it was expected that positive transfer would also be demonstrated relative to the different rule control in the present task under CM conditions. However, Hale and Eggemeier (1990) reported no such transfer under VM conditions. They attributed this failure to the inability of subjects to acquire a consistent response to VM semantic categories during original training. Based on these results, no substantial differences between the two transfer conditions (i.e., untrained exemplars of trained rules versus

different rule control) were expected for those subjects who had been trained under VM or VM/CM conditions.

As in Experiment 1, a portion of this experiment, concerned with the CM and VM/CM conditions, had been completed under the previous phase of this program, and was reported by Eggemeier et al. (1991). The remaining portions were conducted under the present phase of the program. The final data set for the entire study is reported here to provide a single report of the completed experiment.

#### Method

Subjects. Subjects were the same 40 University of Dayton students who participated in Experiment 1. They were paid \$5.00/hour for their participation.

Apparatus. The experiment used the same type of Zenith Data Systems 248 computer and Zenith ZCM-1490 high-resolution, thirteen-inch color monitor used in Experiment 1. Responses were made on the same arrow keys of a standard expanded IBM-compatible keyboard.

Procedure. Subjects performed the same type of memory search task as that performed in Experiment 1. The same target/distractor mapping (CM versus VM/CM versus VM) that a subject had been trained with in Experiment 1 was maintained for that subject throughout this experiment. On each trial, subjects were presented with a memory set of three alphanumeric rules that remained on the CRT screen until they pressed a designated key. These rules, the same type used in Experiment 1, consisted of the conjunction of a three-letter sequence and a range of numerical values. After presentation of the memory set, a fixation cross appeared in the middle of the screen for 500 ms. This cross was replaced by a single test item displayed until either the subject responded or two seconds elapsed. Test items, the same type as

used in Experiment 1, consisted of a three-letter sequence and a single two-digit numeral.

Subjects determined if the test item represented an exemplar of the rules presented in the memory set and responded "yes" or "no" by pressing a labeled response button on the keyboard. Half the items in each block of trials were members of the memory set. Both reaction time and accuracy measures were collected. The same 90-percent criterion level used in Experiment 1 was maintained in this experiment.

Visual feedback was provided to subjects in the same format as in Experiment 1. After each trial, an incorrect response was followed by a "Wrong Response" message. A correct response was followed by a "Correct Response" message and the reaction time for that trial.

Summary feedback was provided at the completion of each block of trials. This feedback provided mean reaction time and accuracy performance levels from the trial block just completed. Summary feedback concerning mean reaction times and accuracy levels was also provided to subjects at the completion of each session. A written tally of mean reaction time and accuracy levels across sessions was made available to subjects as an aid in monitoring progress.

The experiment was divided into two phases: (a) pre-transfer and (b) transfer. The purpose of the pre-transfer phase was to establish a performance baseline that could be used to assess levels of transfer in the subsequent phase and to provide practice to the subjects in search task performance under only the memory set size three condition. Memory sets of three rules were used to increase the potential to detect any transfer differences. Previous research (e.g., Eggemeier et al., 1990, 1991) demonstrated that the effect of automatic processing is most pronounced at higher memory set sizes; therefore, memory

sets of three rules were chosen for use in the current experiment.

Subjects completed two sessions of pre-transfer performance on the day following the completion of Experiment 1. Each pre-transfer session included ten 20-trial blocks, for a total of 400 pre-transfer trials. Memory set size was held constant at three alphanumeric rules. Pre-transfer sessions used the same memory set rules, and the same target and distractor sets used to train each individual subject in Experiment 1. Four CM subjects continued with alphanumeric rules drawn from rule set "A," and exemplars and non-exemplars of those rules that used odd numerical values. Likewise, four additional CM subjects continued with rules drawn from set "A," and even exemplars/non-exemplars. Four other CM subjects continued with rules from set "B" with even exemplars/non-exemplars, while the remaining four CM subjects continued with set "B" rules and odd exemplars/non-exemplars. The sixteen subjects in the VM/CM condition were divided into the same rule/exemplar combinations as the CM subjects and continued with either rule sets "A" or "B," and odd or even exemplars/non-exemplars as appropriate. The eight subjects in the VM condition were also divided into the same rule/exemplar combinations, except that two rather than four VM subjects were assigned to each combination and the conjunction of acronyms and numerical values varied on a trial-by-trial basis.

After completion of pre-transfer, all subjects were transferred to one of two conditions: (a) the Same rules but with Different exemplars (S/D) than had been previously trained, or (b) Different rules and Different exemplars (D/D) than had been previously trained. The first letter group designation indicates whether the alphanumeric rule used at transfer was the same or different from pre-transfer; and the second designation indicates if the exemplar/non-exemplar sets were the same as or different from pre-transfer. Rule changes consisted of changes in both the letter sequences that stood for system parameter

designators and the numerical values associated with the parameters. Exemplar changes involved a change in the values associated with a rule, such that subjects trained with even-valued numerical exemplars were changed to odd-valued exemplars, and vice-versa. D/D conditions involved a change in the letter designators, the associated range of numerical values, and the type of exemplars (even versus odd) presented to subjects. S/D conditions permitted subjects to continue with the same letter designators and range of associated numerical values used in pre-transfer and involved only a change in the type of exemplars (even versus odd) that were presented at transfer.

There were eight CM subjects, eight VM/CM subjects, and four VM subjects assigned to each transfer group. Each group included each combination of rule set and exemplar type used during pre-transfer.

The transfer phase for all subjects consisted of two sessions of ten 20-trial blocks, for a total of 400 trials.

Design. Three independent variables were included in the design: (a) mapping condition (CM, VM/CM, VM), (b) sessions of pre-transfer or transfer trials, and (c) transfer group (S/D or D/D).

### Results

Pre-transfer and transfer data were analyzed separately. In each case, correct responses in sessions of 200 trials were used in the data analyses.

Pre-Transfer Reaction Time. Figure 5-1 shows mean reaction time as a function of mapping condition and transfer group across the two sessions of pre-transfer. As shown in the figure, transfer group did not have a major effect on mean reaction time in any of the mapping conditions. However, the CM group tended

FIRST PRETRANSFER SESSION

SECOND PRETRANSFER SESSION

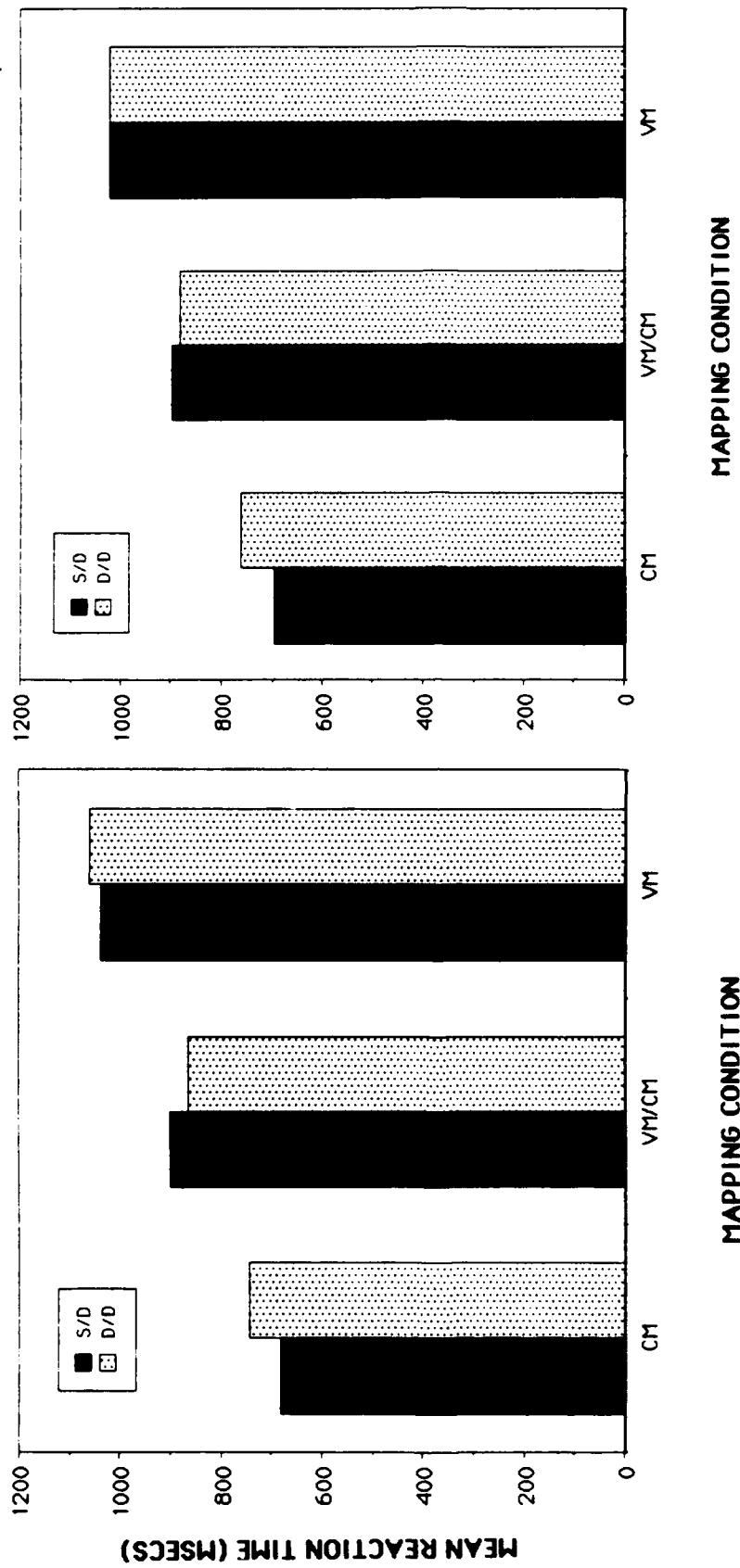


Figure 5-1. Mean Reaction Time as a Function of Mapping Condition, Transfer Group, and Pre-transfer Session.

to exhibit faster reaction times than those associated with the hybrid VM/CM group, which in turn showed faster reaction times than the VM group. Therefore, the ordering of mapping conditions observed at the conclusion of Experiment 1 at the memory set three condition was preserved during the pre-transfer sessions in this experiment.

A  $3 \times 2 \times 2$  ANOVA was conducted on these data to investigate the effects of mapping condition (CM, VM/CM, VM), pre-transfer sessions, and transfer group (S/D or D/D) on reaction time performance. This analysis indicated that the main effect of mapping condition ( $F(2,34) = 11.33$ ,  $p < .001$ ,  $MS_e = 49659.57$ ) was significant, but neither the main effect of transfer group ( $F(1,34) = 0.10$ ,  $p > .05$ ) nor the main effect of pre-transfer sessions ( $F(1,34) = 0.00$ ,  $p > .05$ ) was significant. None of the interactions proved to be reliable. Contrasts performed to follow the main effect of mapping condition showed that the CM condition differed reliably from the hybrid VM/CM condition ( $F(1,34) = 8.84$ ,  $p < .005$ ,  $MS_e = 49659.57$ ) and from the VM condition ( $F(1,34) = 21.22$ ,  $p < .001$ ). The hybrid VM/CM condition also differed reliably from the VM condition ( $F(1,34) = 4.75$ ,  $p < .05$ ).

Pre-transfer Response Accuracy. Figure 5-2 shows mean percent correct as a function of mapping condition, transfer group, and pre-transfer sessions. As illustrated in the figure, neither transfer group nor mapping condition had an appreciable effect on accuracy. Accuracy of responding was consistently high and, particularly in the CM and VM/CM conditions, approximated the 90-percent criterion that had been established for subjects.

A  $3 \times 2 \times 2$  ANOVA was conducted on the percent correct data to investigate the effects of mapping condition, pre-transfer sessions, and transfer group on percent correct performance. This analysis indicated that the main effects of mapping

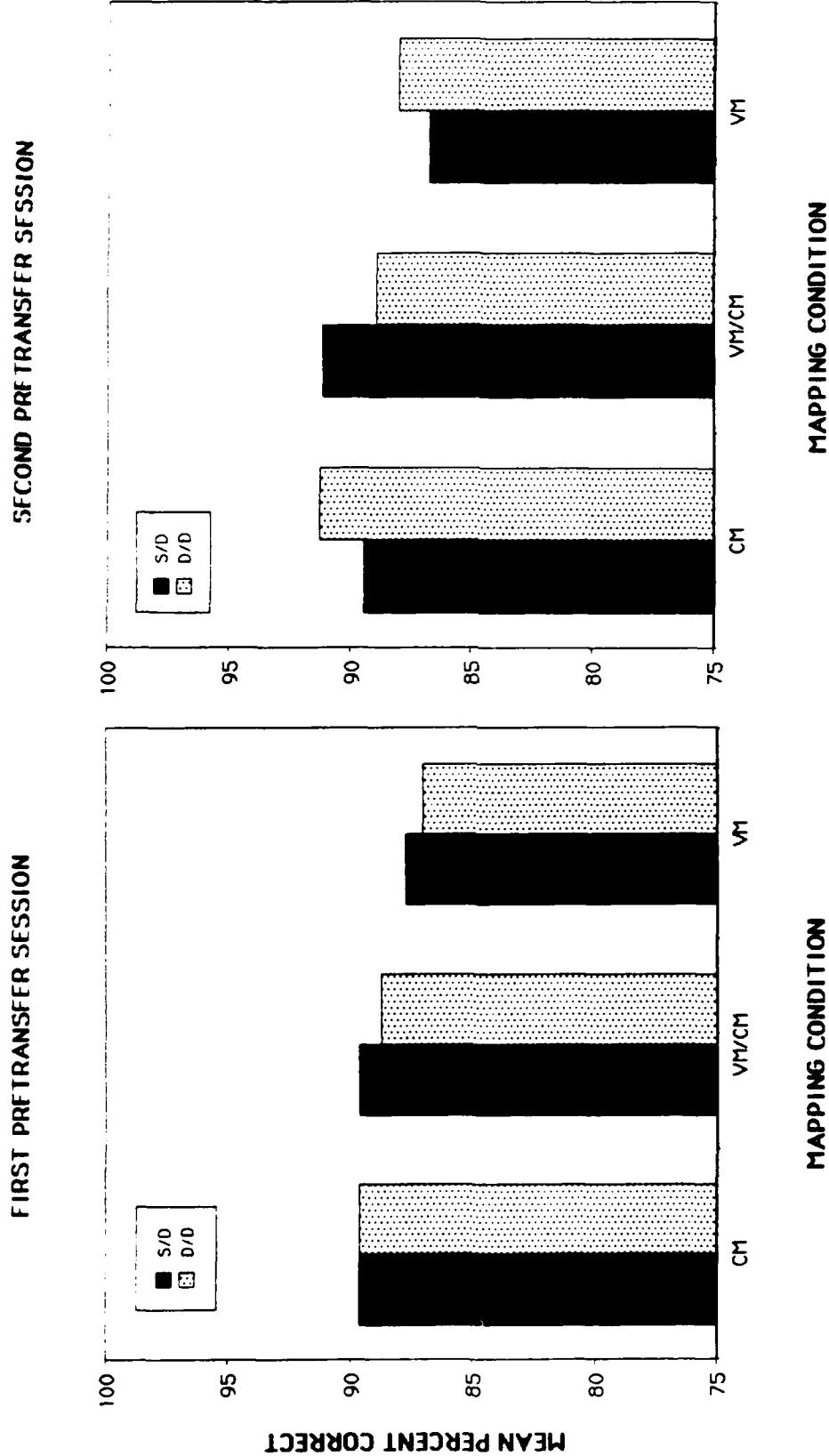


Figure 5-2. Mean Percent Correct as a Function of Mapping Condition, Transfer Group, and Pre-transfer Session.

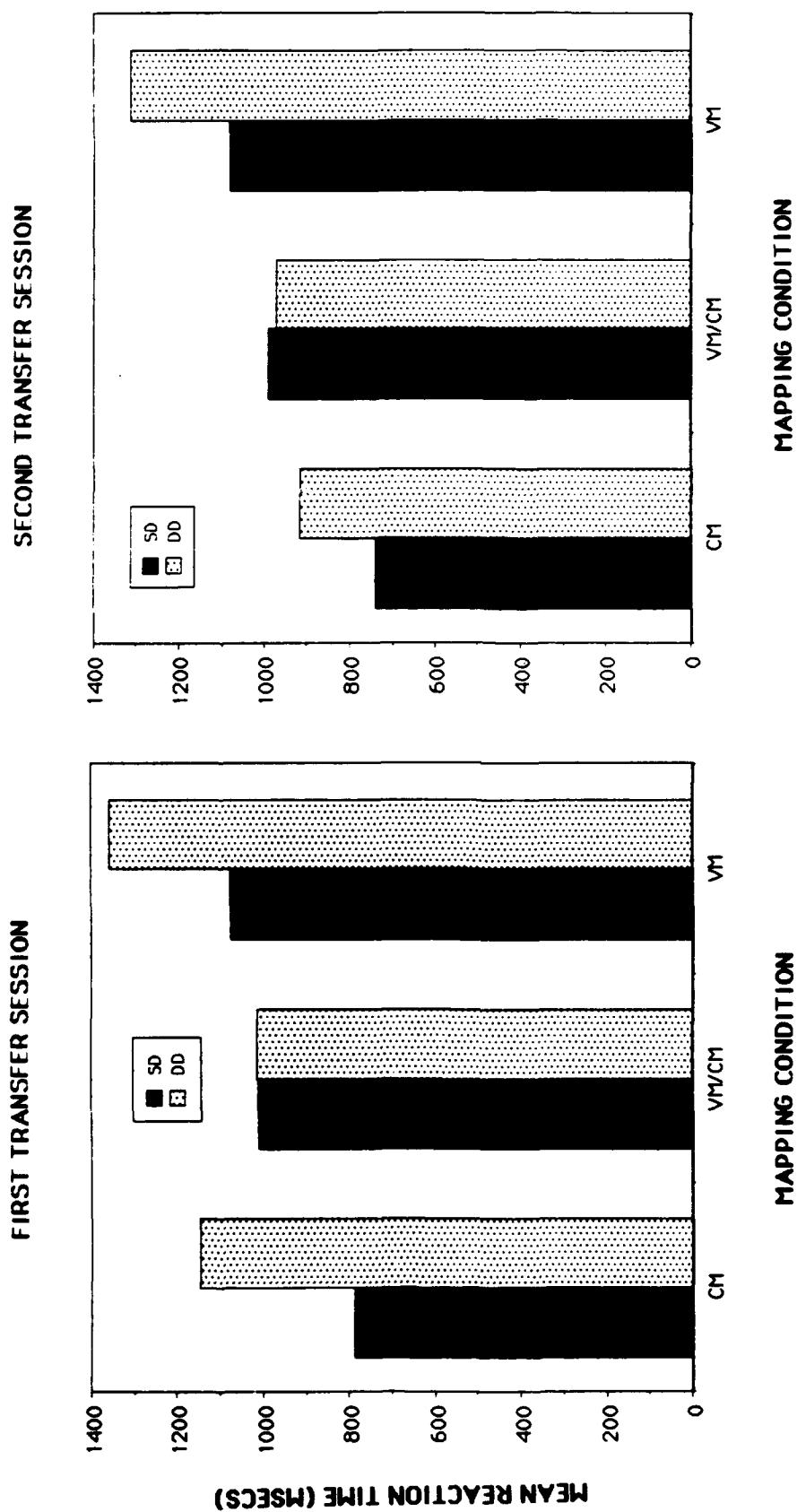
condition ( $F(2,34) = 3.03, p > .05, MS_e = 12.61$ ), transfer group ( $F(2,34) = 0.02, p > .05$ ), and pre-transfer sessions ( $F(1,34) = 1.35, p > .05, MS_e = 3.33$ ) were not reliable. None of the interactions proved to be significant.

The absence of any significant effect involving transfer groups in both analyses indicates that there were no reliable differences in the accuracy or speed of performance between the transfer groups at the conclusion of the pre-transfer portion of the experiment. Therefore, these results facilitate the interpretation of any differences between groups that might occur in the subsequent transfer phase.

Transfer Reaction Time. Figure 5-3 shows mean reaction time as a function of mapping condition, transfer condition, and transfer sessions. As illustrated in the figure, the S/D versus D/D transfer conditions appear to have had their most marked effect within the CM condition, with the S/D group demonstrating lower reaction times than the D/D group.

Relative to pre-transfer baselines, there was negative transfer in all conditions. Negative transfer has been obtained in a number of previous experiments (Hale and Eggemeier, 1990; Hassoun and Eggemeier, 1988) that employed the S/D and D/D conditions. Using the last pre-transfer session as a baseline, the CM-SD condition showed an 89-ms mean decrement versus a 387-ms decrement in the CM-D/D condition during the first transfer session. Comparable decrements in the VM condition were 54 ms and 332 ms in the S/D and D/D conditions, respectively. Within the VM/CM condition, transfer resulted in mean first transfer session decrements of 113 ms in the S/D condition, and 128 ms in the D/D condition.

A  $3 \times 2 \times 2$  ANOVA was performed on the reaction time data shown in Figure 5-3. The purpose of this analysis was to investigate S/D versus D/D differences as a function of mapping



**Figure 5-3.** Mean Reaction Time as a Function of Mapping Condition, Transfer Group, and Transfer Session.

condition and transfer session. The ANOVA showed that the main effect of mapping condition ( $F(2,34) = 8.58, p < .01$ ,  $MS_e = 59331.70$ ) was significant, as were the main effects of transfer condition ( $F(1,34) = 9.10, p < .01$ ) and transfer session ( $F(1,34) = 18.41, p < .01, MS_e = 3965.8$ ). The analysis also indicated that the interactions of mapping condition and transfer session ( $F(2,34) = 7.65, p < .01$ ), transfer condition and transfer session ( $F(1,34) = 7.76, p < .01$ ), and the three-way interaction of mapping condition, transfer condition, and transfer session ( $F(2,34) = 3.80, p < .05$ ) were reliable.

To further investigate the significant three-way interaction, a  $3 \times 2$  ANOVA was performed to assess the effects of mapping condition and transfer condition within the first and second transfer sessions. The ANOVA performed on the data of the first transfer session indicated that the main effects of mapping condition ( $F(2,34) = 4.48, p < .05, MS_e = 38556.24$ ) and transfer condition ( $F(1,34) = 10.75, p < .01$ ) were significant, as was the mapping condition and transfer condition interaction ( $F(2,34) = 3.59, p < .05$ ). A comparable ANOVA performed on the second transfer session data showed that the main effects of mapping condition ( $F(2,34) = 14.83, p < .001, MS_e = 24741.26$ ) and transfer condition ( $F(1,34) = 6.33, p < .01$ ) were reliable, but the mapping condition and transfer condition interaction ( $F(2,34) = 2.29, p > .05$ ) was not.

To assess the interaction of mapping condition and transfer condition that was present during the first transfer session, tests of the simple effects of transfer condition were conducted within each mapping condition. These analyses showed a reliable effect of transfer condition within the CM group ( $F(1,34) = 13.66, p < .01$ ), but failed to show significant transfer condition effects in either the VM/CM ( $F(1,34) = 0.00, p > .05$ ) or VM ( $F(1,34) = 4.05, p > .05$ ) conditions.

The results indicate that in the first transfer session only the CM group showed reliable positive S/D transfer relative to the D/D condition -- although there was a substantial trend for the VM condition to do so as well. The positive transfer in the CM condition is noteworthy because it indicates that the automatic processing benefits established during training were applicable to untrained exemplars of trained rules. No differences between transfer conditions were expected under the VM and hybrid VM/CM conditions because the inconsistency in application of the rules as target and distractors during training should have precluded substantial rule-response learning.

Contrasts conducted to follow-up the main effect of mapping condition within the second transfer session indicated that the CM condition differed reliably from the hybrid VM/CM ( $F(1,34) = 7.65$ ,  $p < .01$ ,  $MS_e = 24741.26$ ) and VM ( $F(1,34) = 29.28$ ,  $p < .01$ ) conditions. The hybrid VM/CM condition was also significantly different from the VM condition ( $F(1,34) = 9.94$ ,  $p < .01$ ). The main effect of transfer condition within the second transfer session reflects the overall tendency of the S/D condition to produce lower reaction times than in the D/D condition.

Transfer Response Accuracy. Mean percent correct responses as a function of mapping condition, transfer condition, and transfer sessions are shown in Figure 5-4. As illustrated by the figure, accuracy of responding was consistently high within the CM and VM/CM conditions, but showed some decrement in the VM condition.

The percent correct response data for the transfer sessions were also subjected to a  $3 \times 2 \times 2$  ANOVA. The results of the ANOVA showed that there was a main effect of mapping condition ( $F(2,34) = 7.93$ ,  $p < .005$ ,  $MS_e = 16.06$ ), but did not demonstrate reliable main effects of transfer condition ( $F(1,34) = 0.30$ ,

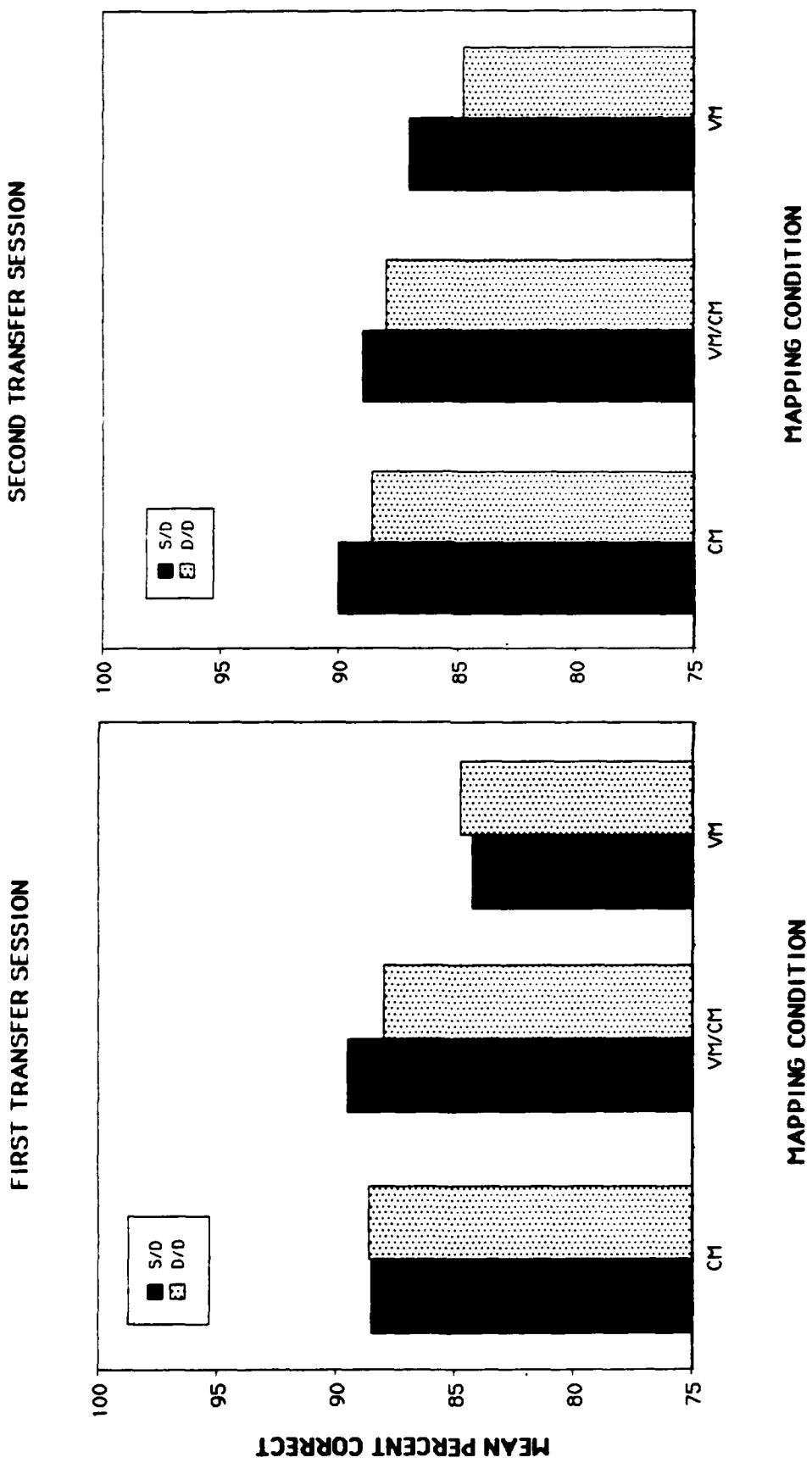


Figure 5-4. Mean Percent Correct as a Function of Mapping Condition, Transfer Group, and Transfer Session.

$p > .05$ ) or transfer session ( $F(1,34) = 3.75$ ,  $p > .05$ ,  $MS_e = 5.00$ ). None of the interactions were significant. The main effect of mapping condition reflects the trend for the VM group to demonstrate lower performance levels than either the CM or VM/CM groups, which showed approximately equal levels of accuracy performance across transfer sessions. The failure to find significant differences involving the transfer condition effect indicates there were no speed/accuracy tradeoffs that would affect interpretation of the previously reported transfer group reaction time results.

### Discussion

The results of this experiment demonstrated positive transfer within the CM group under S/D versus D/D conditions; this indicates reliable transfer to untrained exemplars of trained rules within the CM condition. These results are consistent with some previous experiments (e.g., Hale and Eggemeier, 1990) that examined transfer of trained semantic categories to untrained exemplars, and indicate that the learning that occurred during original training can be at least partially attributed to the level of the alphanumeric rules rather than the level of individual exemplars.

The failure to find any evidence of rule-level learning within the hybrid VM/CM condition is also consistent with the Hale and Eggemeier (1990) study. The Hale and Eggemeier (1990) study employed a VM condition analogous to the current hybrid condition; that is, semantic category exemplars were consistently mapped to their respective categories across trials. The lack of positive transfer within their hybrid condition was attributed by Hale and Eggemeier (1990) to the inability of subjects to consistently associate a response to a particular semantic category in their study. The same interpretation can be applied to the failure of the VM/CM group to demonstrate positive S/D transfer in the present experiment.

Although the differences between the S/D and D/D conditions within the VM group were not of sufficient magnitude to be statistically significant in the first transfer session, there was some trend for positive transfer in the S/D condition. This trend continued in the second transfer session and is somewhat surprising, given the nature of the present VM condition that should have precluded any specific rule/exemplar learning. The design of the present experiment does not permit identification of the factor(s) that may have been responsible for the trend. Future research that incorporates different levels of consistency into a transfer task should continue to document performance under conditions that are inconsistent at both the rule and rule/exemplar levels. If the present trend continues, the factor(s) responsible should be investigated.

Experiment 6  
Transfer of Training with Complex Alphanumeric Materials  
in a Hybrid Visual/Memory Search Task

Purpose

The purpose of this experiment was to investigate the transfer of CM and VM training to untrained exemplars of previously trained rules in the complex alphanumeric visual/memory search task investigated in Experiment 2. This experiment, which employed a visual/memory search task, is an extension of the memory search work performed in Experiment 5. The issue of transfer from one subset of the rule exemplars to another has important practical implications for the design of training programs. It is also of theoretical importance because positive transfer to untrained exemplars of a rule would provide evidence that the skill acquired during training was at the level of the rule rather than the subset of exemplars. Consequently, the present Experiment 6 evaluated the performance level that would result when subjects trained in the alphanumeric rule

visual/memory search task of Experiment 2 were transferred to untrained exemplars of trained rules. A control condition which involved transfer to a task that required the processing of completely different rules and exemplar sets was also incorporated into the design.

Based upon the results of Experiment 5 in rule-based memory search and on previous work with semantic category search (e.g., Hale and Eggemeier, 1990; Hassoun and Eggemeier, 1988; Schneider and Fisk, 1984), it was expected that positive transfer would be demonstrated relative to the different rule control in the present task under CM training conditions. The results of Experiment 5 and those of Hale and Eggemeier (1990) also indicated that no significant differences between the two transfer conditions should be expected following VM training.

In addition to evaluating the performance levels that would result under the two transfer conditions, this experiment investigated the workload associated with transfer. As in Experiment 2, the NASA TLX (Hart and Staveland, 1988) rating scale procedure was used to evaluate workload. Based upon the expectation that transfer of trained rules to untrained exemplars would permit subjects to continue utilizing previously developed automatic processing, it was anticipated that such transfer under CM conditions would be associated with lower workload levels than transfer to untrained exemplars of untrained rules or to transfer under VM conditions.

#### Method

Subjects. Subjects were the same eight University of Dayton students who participated in Experiment 2. They were paid \$3.75/hour, plus a \$1.25/hour bonus for prompt attendance at all sessions.

Apparatus. The experiment used the same type of Zenith Data Systems 248 computer and Zenith ZCM-1490 high-resolution, thirteen-inch color monitor used in Experiment 2. Responses were made on the same numeric keys of the standard expanded IBM-compatible keyboard used previously.

Procedure. Subjects performed the same type of visual/memory search task trained in Experiment 2. The same target/distractor mappings (CM or VM) were also employed. On each trial, subjects were presented with a memory set of one to four alphanumeric rules that remained on the CRT screen until the subject pressed a designated key. These rules were the same type used in Experiment 2 and consisted of the conjunction of a three-letter sequence and a range of numerical values. After presentation of the memory set, a test display consisting of four test items arranged in a quadrant was presented until either the subject responded or 5 seconds elapsed. Individual test items were the same type as used in Experiment 2 and consisted of a three-letter sequence and a single two-digit numeral.

As in Experiment 2, subjects determined which of the four test items represented an exemplar of one of the rules presented in the memory set and responded by pressing the numeric key that indicated the spatial position of the critical test item within the test display quadrant. An exemplar of one of the memory set rules was present on each trial, along with three non-target or distractor exemplars. For half the trials, one of these distractors represented a non-target instance of one of the memory set rules, while the remaining two distractors represented instances of rules that had not appeared in the memory set. In the remaining trials, two of these distractors represented instances of a single rule that had not appeared in the memory set, while the third represented an additional non-memory set rule. This procedure was intended to preclude a subject from responding correctly across trials on the basis of either single component (i.e., three-letter sequence or numerical value) of the

rules. Both reaction time and accuracy measures were collected. The same 90-percent correct performance criterion level used in Experiment 2 was maintained in this experiment.

NASA TLX workload ratings were completed by subjects at the end of each session. They rated the workload associated with performance of the visual/memory search task under both CM and VM conditions using standard TLX procedures. These procedures required the completion of separate ratings for each of the six TLX dimensions. Subjects first rated the last block of trials completed, then provided ratings on the next to last block of trials completed. Thus, half the subjects rated the CM condition followed by the VM condition, while the remaining subjects rated the VM condition first and the CM condition second.

Visual feedback was provided to subjects in the same format as in Experiment 2. After each trial, an incorrect response was followed by an "Incorrect Response" message and the reaction time for the trial. A correct response was followed by a "Correct Response" message and the reaction time for that trial.

Summary feedback, presented at the completion of each block of trials, provided mean reaction time and accuracy performance levels from the trial block just completed. Summary feedback concerning mean reaction times and accuracy levels was also provided to subjects at the completion of each session. A written tally of mean reaction time and accuracy levels across blocks of trials was maintained by subjects as an aid in monitoring progress across sessions.

Subjects completed two sessions of transfer on two separate days. All subjects were transferred to either an S/D or D/D condition. As in Experiment 5, the first letter group designation indicates whether the alphanumeric rules used at transfer were the same as those used during training; the second designation indicates whether the exemplar/non-exemplar sets were

the same as those trained. Rule changes consisted of changes in both the letter sequences that stood for system parameter designators and the numerical values associated with the parameters. Exemplar changes involved a change in the values associated with a rule, such that subjects trained with even-valued numerical exemplars were changed to odd-valued exemplars, and vice-versa. Therefore, D/D conditions involved a change in the letter designators, the associated range of numerical values, and the type of exemplars (even versus odd) presented to subjects. Meanwhile, S/D conditions permitted subjects to continue with the same letter designators and range of associated numerical values used in pre-transfer, and involved only a change in the type of exemplars (even versus odd) presented at transfer.

Four subjects were assigned to each transfer group. Each transfer group included an equal number of instances of each of the four rule sets used during training. Rule sets appeared an equal number of times under CM and VM conditions within each transfer group. Half the subjects in each transfer group first performed a CM block of trials followed by a VM block of trials. This presentation order was continued throughout the transfer session. The remaining subjects in each transfer group performed the trials in the opposite order (i.e., received a VM trial block followed by a CM trial block).

The transfer phase for all subjects consisted of two sessions of eight 40-trial blocks, for a total of 640 transfer trials.

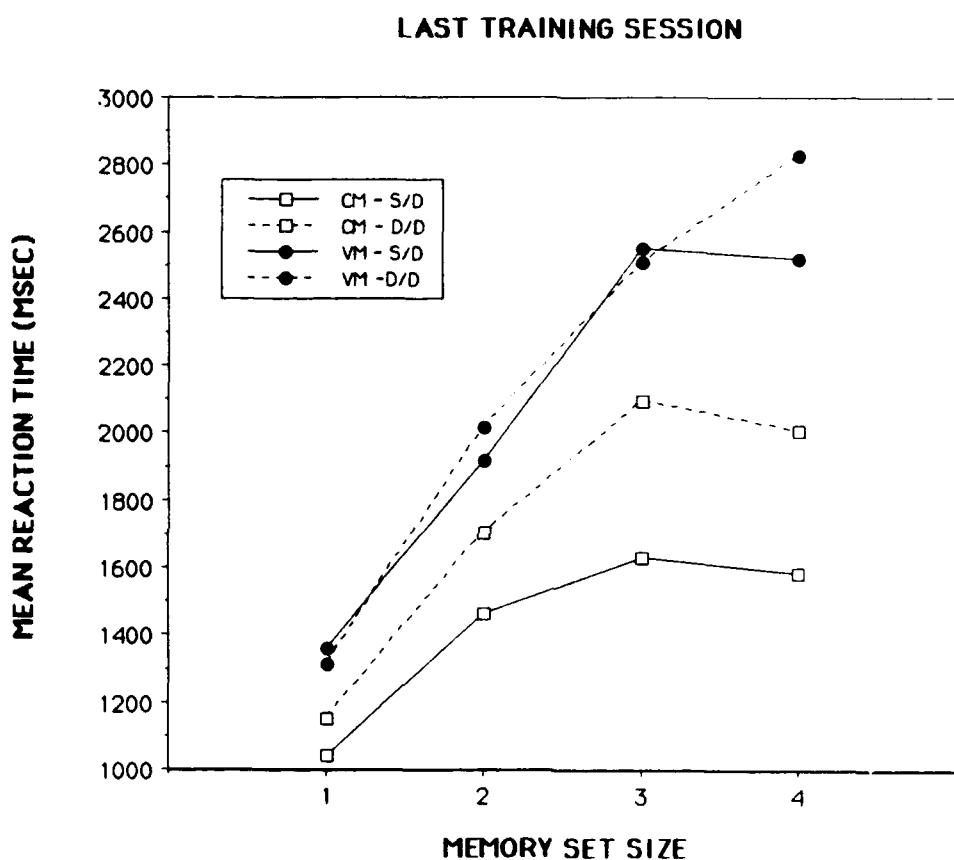
Design. Four independent variables were included in the design: (a) mapping condition (CM or VM), (b) sessions of transfer trials (1-2), (c) memory set size (1-4), and (d) transfer group (S/D or D/D). The former three were within-subjects variables, while transfer group represented a between-subjects variable.

## Results

The last session of training from Experiment 2 served as a pre-transfer baseline to evaluate the performance of subjects who were eventually assigned to the S/D and D/D transfer conditions. Subjects were assigned to these conditions at random. Assignment was completed before analyses of the data from Experiment 2 had been performed. The analysis of the Session 10 data from Experiment 2 served as a post-hoc test of the performance levels of those subjects who had transferred to different conditions.

Pre-transfer Reaction Time. Figure 6-1 shows mean reaction time as a function of mapping condition, memory set size, and transfer group during the last training session of Experiment 2. Reaction times in the figure are based upon correct responses. As depicted in the figure, the CM condition was associated with lower reaction times than the VM condition. Also, under CM conditions, there was some trend for S/D subjects to exhibit lower reaction times than D/D subjects.

A 2 x 4 x 2 ANOVA was conducted on these data to investigate the effects of mapping condition (CM versus VM), memory set size (1-4), and transfer group (S/D versus D/D) on reaction time performance. This analysis showed that the main effects of mapping condition ( $F(1,6) = 27.93$ ,  $p < .005$ ,  $MS_e = 168830.18$ ) and memory set size ( $F(3,18) = 85.89$ ,  $p < .001$ ,  $MS_e = 42087.63$ ) were reliable, but that the main effect of transfer group ( $F(1,6) = 0.57$ ,  $p > .05$ ,  $MS_e = 1040153.8$ ) was not. As expected, the interaction of mapping condition and memory set ( $F(3,18) = 12.37$ ,  $p < .001$ ,  $MS_e = 26417.63$ ) was significant, but none of the other interactions were reliable. The significant interaction reflects the greater attenuation of the memory set size effect in the CM versus VM condition, which was discussed in conjunction with the Experiment 2 data analyses. The principal result of interest from the present analysis is the failure to find reliable differences between the S/D and D/D groups at the



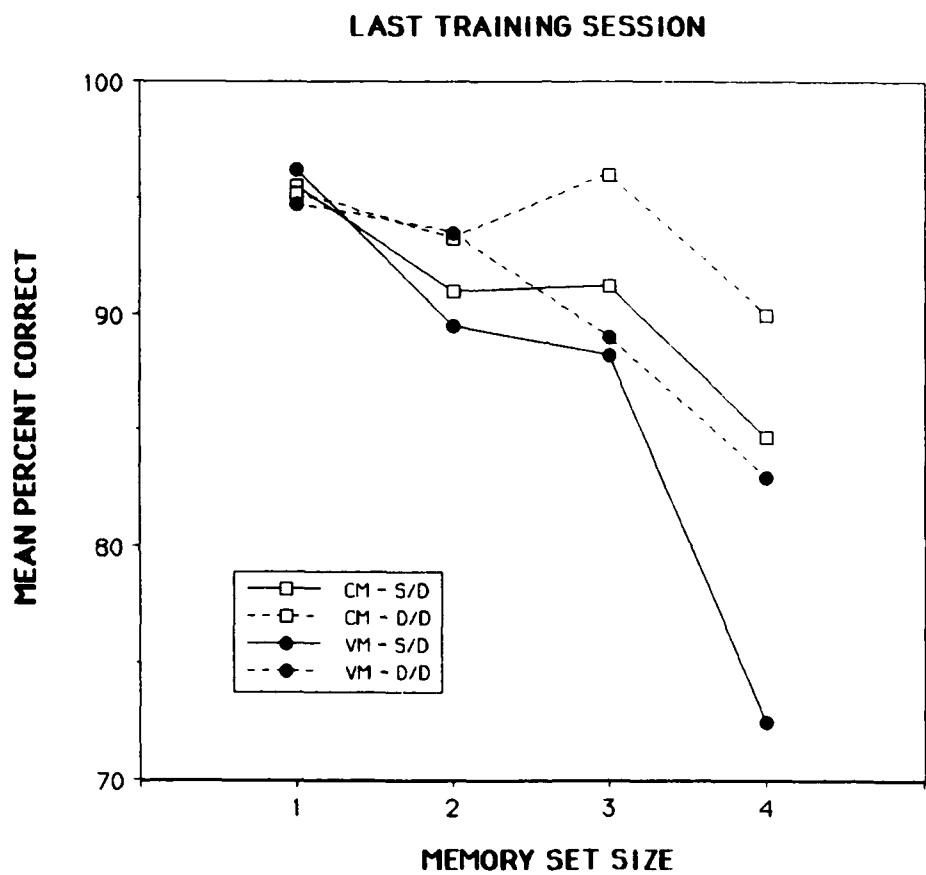
**Figure 6-1.** Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Transfer Group.

conclusion of original training. This result indicates that there were no significant reaction time differences between the transfer groups at the conclusion of training and therefore facilitates interpretation of the reaction time data obtained under transfer conditions.

Pre-transfer Response Accuracy. Figure 6-2 illustrates mean percent correct as a function of mapping condition, memory set size, and transfer group during the last training session of Experiment 2. As shown in the figure, the CM condition was associated with higher accuracy levels than the VM condition, particularly at the larger memory set sizes. There is also a trend for the D/D group to demonstrate higher levels of accuracy; this trend is somewhat more pronounced at the larger memory set sizes.

A  $2 \times 4 \times 2$  ANOVA, comparable to the reaction time analysis, was conducted on the percent correct data to investigate the effects of mapping condition, memory set size, and transfer group on percent correct performance. This analysis indicated that the main effects of mapping condition ( $F(1,6) = 25.26, p < .005$ ,  $MS_e = 9.06$ ), memory set size ( $F(3,18) = 9.40, p < .005$ ,  $MS_e = 50.61$ ), and transfer group ( $F(1,6) = 6.58, p < .05$ ,  $MS_e = 25.18$ ) were significant. Once again, the interaction of mapping condition and memory set was reliable ( $F(3,18) = 3.21, p < .005$ ,  $MS_e = 25.27$ ), but none of the other interactions were significant. As in the reaction time analysis, the significant mapping condition and memory set size interaction was expected and reflects a greater attenuation of the memory set size effect within the CM versus VM condition.

The main effect of transfer condition confirms the previously noted tendency for the D/D group to exhibit more accurate performance than the S/D group. This difference indicates that higher levels of performance accuracy were achieved by D/D subjects at the conclusion of training. However,

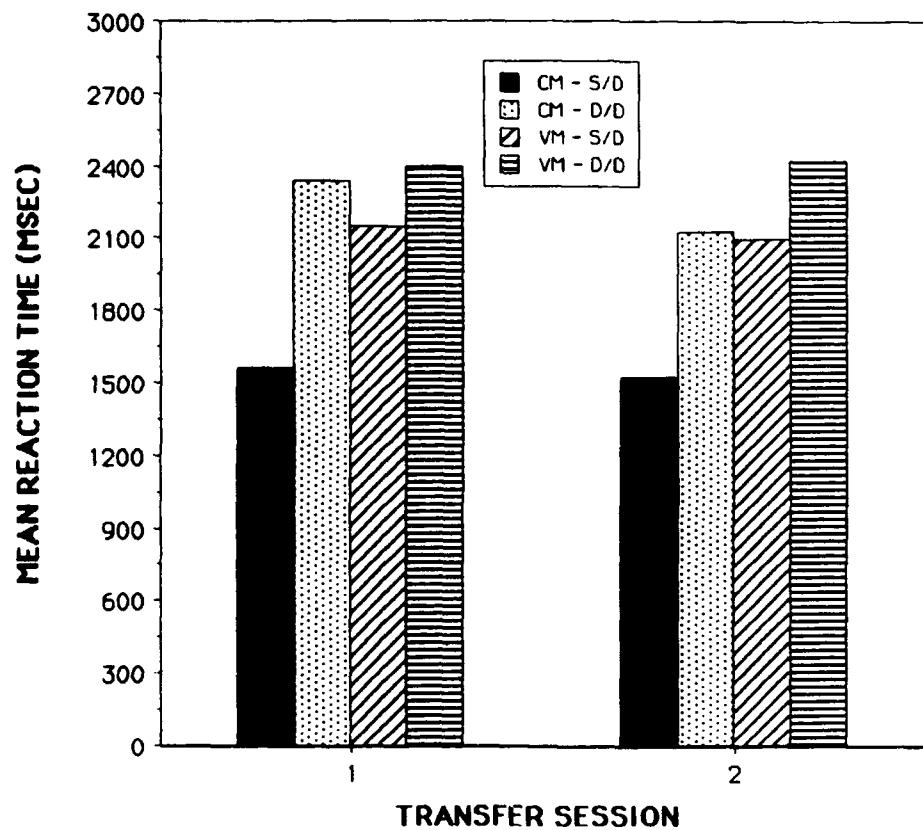


**Figure 6-2.** Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Transfer Group.

such a difference was not considered of major importance in interpreting the transfer data because lower levels of D/D performance relative to S/D performance had been predicted at transfer. In effect, this result suggests that tests of S/D versus D/D transfer accuracy differences would favor the D/D group relative to the S/D group. The results of the pre-transfer analyses indicate that there were no differences between groups that would favor the S/D group and pose interpretation problems associated with the anticipated superiority of that group relative to the D/D group at transfer.

Transfer Reaction Time. Figure 6-3 illustrates mean reaction time as a function of mapping condition, transfer condition, and transfer sessions. Reaction times are based upon correct responses. As shown in the figure, the S/D versus D/D transfer conditions appear to have had a differential effect on performance within the CM condition but relatively little effect within the VM condition. While S/D transfer in the CM condition produced the fastest reaction times when compared to all other conditions, D/D transfer in the CM condition resulted in performance levels that approximated VM levels. This latter finding suggests that the reaction time advantages associated with CM training were no longer present in the CM-D/D condition. Transfer session does not appear to have had a marked effect on reaction times.

Relative to the pre-transfer baselines provided by the last session of original training, there was negative transfer in all conditions. This result was expected and is consistent with data from Experiment 5 and other experiments (Hale and Eggemeier, 1990; Hassoun and Eggemeier, 1988) that have used the S/D and D/D conditions. Using the last original training session as a baseline, the CM-S/D condition resulted in a mean decrement of 131 ms versus a 598-ms mean decrement in the CM-D/D condition during the first transfer session. Comparable first transfer session decrements in the VM condition were 62 ms and 231 ms in



**Figure 6-3.** Mean Reaction Time as a Function of Mapping Condition, Transfer Group, and Transfer Session.

the S/D and D/D conditions, respectively. It is important to note that, despite these decrements, the CM-S/D condition produced mean reaction times during the initial transfer session that were almost 600 ms faster than the comparable VM condition.

A 2 x 4 x 2 x 2 ANOVA was performed on the reaction time data. This analysis investigated S/D versus D/D differences as a function of memory set size, mapping condition, and transfer session. Transfer group was a between-subjects variable in the analysis, while memory set size, mapping condition, and sessions represented within-subjects variables. The ANOVA revealed that the main effects of mapping condition ( $F(1,6) = 43.02$ ,  $p < .005$ ,  $MS_e = 106333.20$ ) and memory set ( $F(3,18) = 359.78$ ,  $p < .001$ ,  $MS_e = 25981.51$ ) were significant, but the main effects of transfer group ( $F(1,6) = 4.13$ ,  $p > .05$ ,  $MS_e = 1854488.0$ ) and transfer sessions ( $F(1,6) = 3.53$ ,  $p > .05$ ,  $MS_e = 46543.41$ ) were not. The interactions of mapping condition and transfer group ( $F(1,6) = 12.44$ ,  $p < .05$ ), transfer group and memory set size ( $F(3,18) = 6.26$ ,  $p < .005$ ), and mapping condition and memory set size ( $F(3,18) = 14.81$ ,  $p < .001$ ,  $MS_e = 38015.99$ ) also proved to be significant. None of the other interactions were reliable.

Figure 6-4 shows mean reaction time as a function of transfer group and mapping condition. As seen in the figure under the CM condition, S/D reaction times were lower than D/D reaction times. However, the difference between the two transfer groups was much less pronounced under the VM condition. To further investigate the significant interaction of mapping condition and transfer group, an analysis of the effect of transfer group was performed within the CM and VM conditions. These analyses demonstrated that the effect of transfer group was significant within the CM condition ( $F(1,6) = 8.33$ ,  $p < .05$ ,  $MS_e = 920806.72$ ) but not within the VM condition ( $F(1,6) = 1.26$ ,  $p > .05$ ,  $MS_e = 1040014.5$ ). Therefore, the noted trend for faster reaction times in the S/D versus the D/D group under the CM condition was reliable.

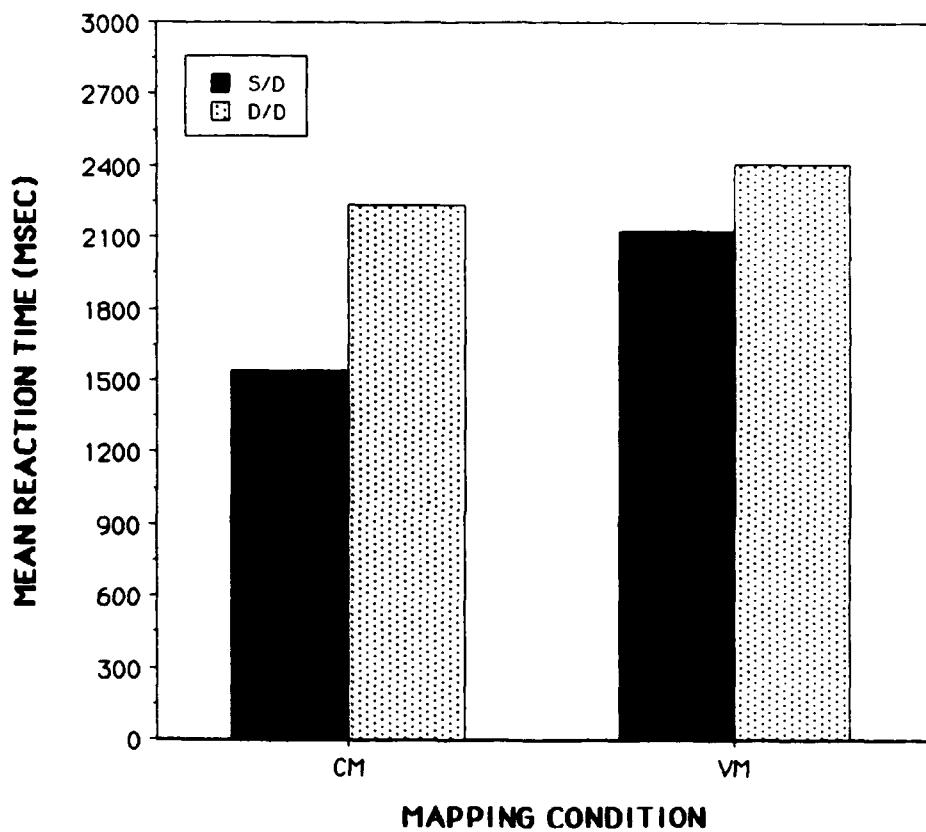
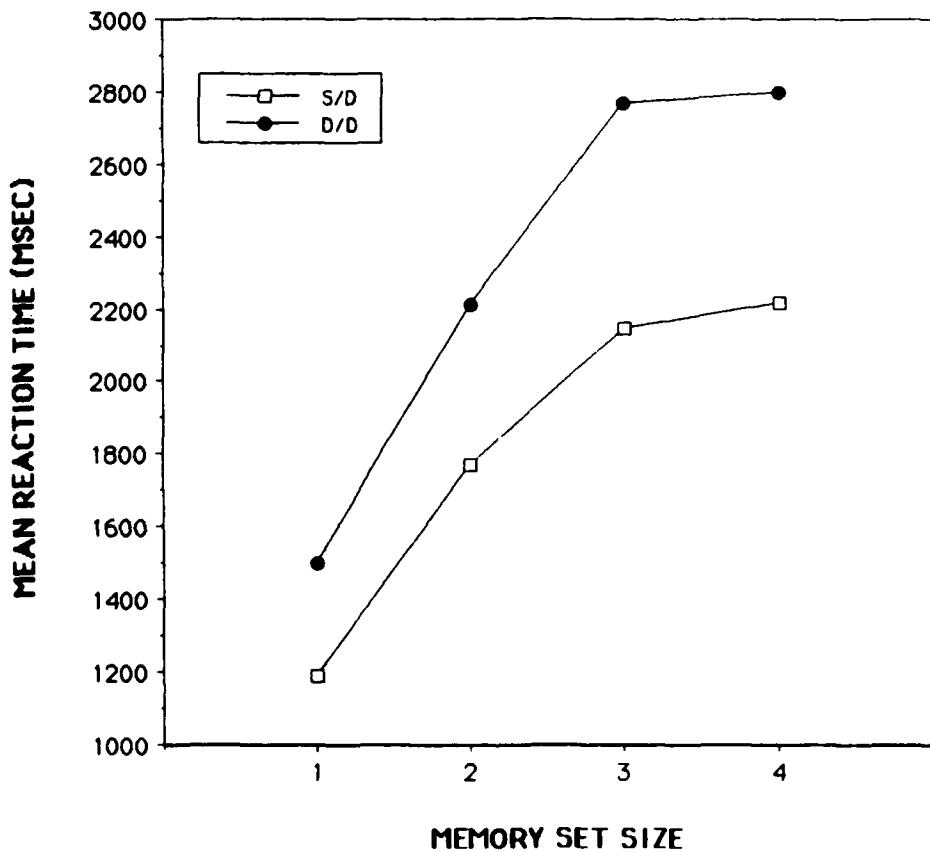


Figure 6-4. Mean Reaction Time as a Function of Mapping Condition and Transfer Group.

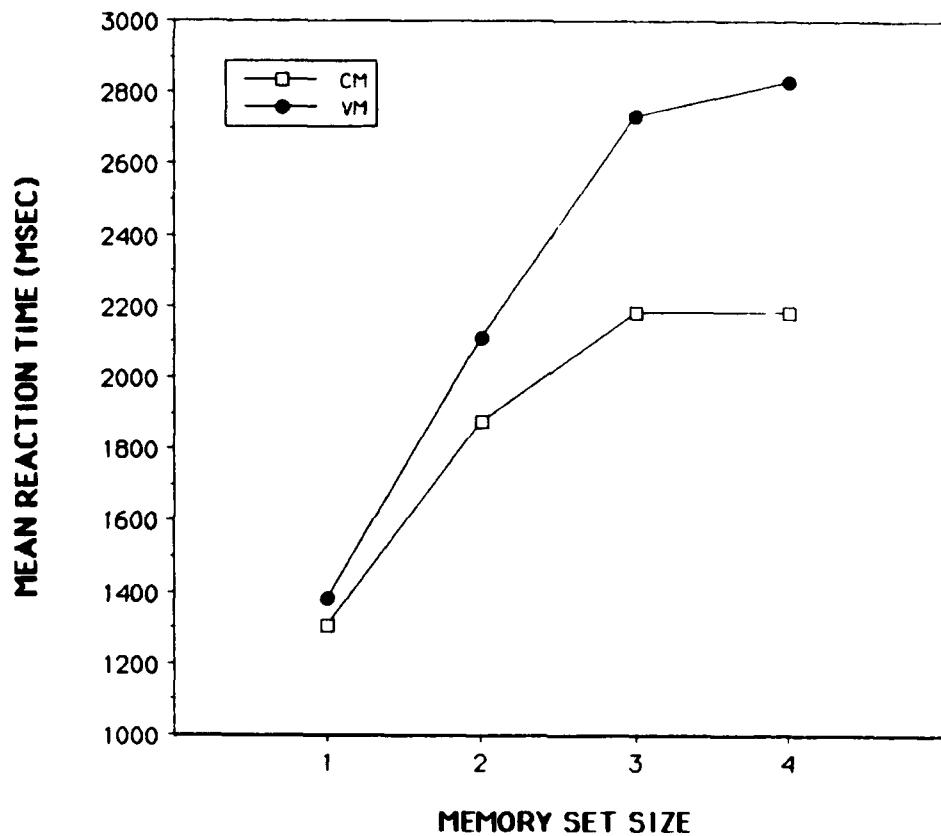
Figure 6-5 shows mean reaction time as a function of transfer group and memory set size. As illustrated in the figure, transfer group exerted a larger effect on performance at the higher memory set sizes. To investigate the reliable interaction of transfer group and memory set size, tests of the transfer group effect were performed at each memory set level. These analyses indicated that the transfer group effect was reliable at memory set size three ( $F(1,6) = 6.07$ ,  $p < .05$ ,  $MS_e = 509893.92$ ) and that the  $F$  value within the memory set size four condition approached but did not attain the level required for significance ( $F(1,6) = 4.29$ ,  $p > .05$ ,  $MS_e = 623648.15$ ). The effect of transfer group was non-significant within both the memory set size one ( $F(1,6) = 2.37$ ,  $p > .05$ ,  $MS_e = 327664.23$ ) and memory set size two ( $F(1,6) = 3.25$ ,  $p > .05$ ,  $MS_e = 471226.25$ ) conditions.

The interaction of mapping condition and memory set also proved reliable in the overall analysis. Figure 6-6 shows mean reaction time as a function of memory set size and mapping condition. The figure demonstrates that memory set exerted a less marked effect on reaction time within the CM condition as compared to the VM condition. This effect is expected and characteristic of some level of automatic processing within the CM condition. To assess the interaction of mapping condition and memory set, tests of the memory set effect were conducted within the CM and VM conditions. These analyses indicated that the effect of memory set was reliable within both the CM ( $F(3,18) = 175.31$ ,  $p < .001$ ,  $MS_e = 15726.97$ ) and VM ( $F(3,18) = 148.20$ ,  $p < .001$ ,  $MS_e = 48270.53$ ) conditions. Although memory set exerted significant effects within both the CM and VM conditions, Figure 6-6 illustrates that the effect on VM performance was more pronounced than on CM performance. This difference is reflected in the reliable interaction.

The results of principal interest indicate that only the CM group showed reliable positive S/D transfer relative to the D/D



**Figure 6-5.** Mean Reaction Time as a Function of Transfer Group and Memory Set Size.

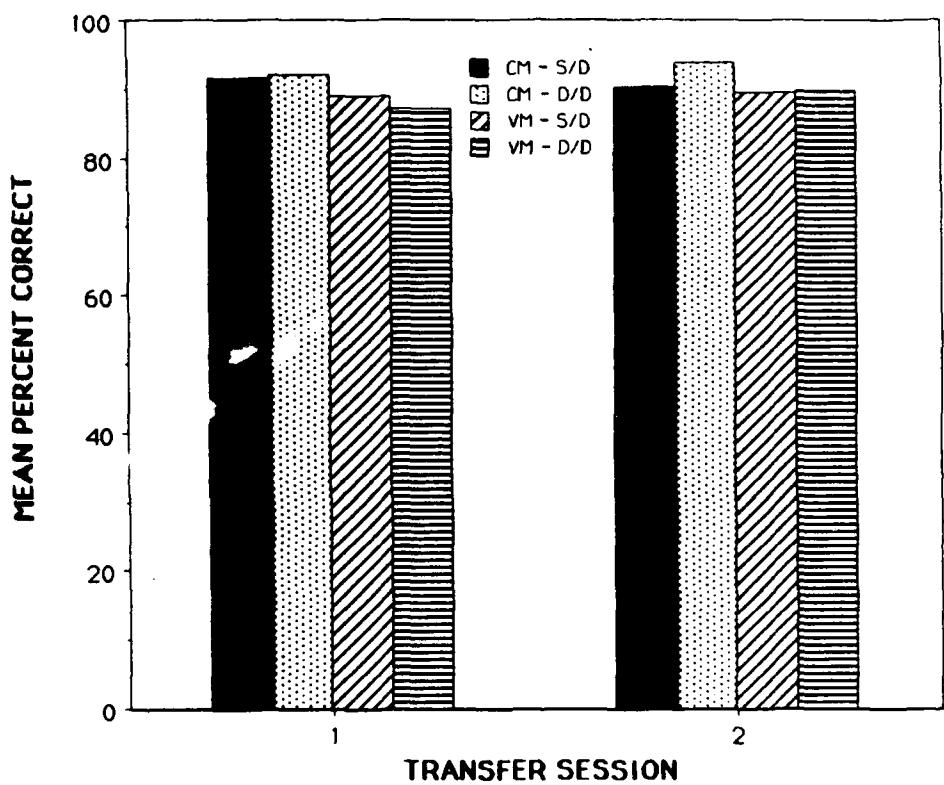


**Figure 6-6.** Mean Reaction Time as a Function of Mapping Condition and Memory Set Size.

condition. The positive transfer indicates that some automatic processing benefits established during training were applicable to untrained exemplars of trained rules. This transfer further suggests that the automatic processing established during original training was at least partially at the rule level rather than the individual exemplar level. No differences in transfer condition had been anticipated under the VM condition because the inconsistency in application of the rules as targets and distractors during training had been expected to preclude substantial rule-response learning.

Transfer Response Accuracy. Mean percent correct responses as a function of mapping condition, transfer condition, and transfer sessions are illustrated in Figure 6-7. As seen in the figure, accuracy of response was consistently high within both transfer conditions and remained relatively constant across sessions. There was also a tendency for CM accuracy to exceed VM accuracy.

A  $2 \times 4 \times 2 \times 2$  ANOVA, comparable to the reaction time analysis, was performed on the percent correct data. This analysis included mapping condition, memory set size, transfer group, and transfer sessions as variables. Transfer group was a between-subjects variable in the analysis; the remaining factors were within-subjects variables. The ANOVA showed that the main effects of mapping condition ( $F(1,6) = 6.35$ ,  $p < .05$ ,  $MS_e = 47.29$ ) and memory set ( $F(3,18) = 15.96$ ,  $p < .001$ ,  $MS_e = 82.20$ ) were reliable, but that the main effects of transfer group ( $F(1,6) = 0.13$ ,  $p > .05$ ,  $MS_e = 98.68$ ) and transfer sessions ( $F(1,6) = 2.16$ ,  $p > .05$ ,  $MS_e = 12.99$ ) were not. The interaction of mapping condition and memory set ( $F(3,18) = 27.28$ ,  $p < .001$ ,  $MS_e = 13.27$ ) was also significant, but none of the other interactions were reliable.

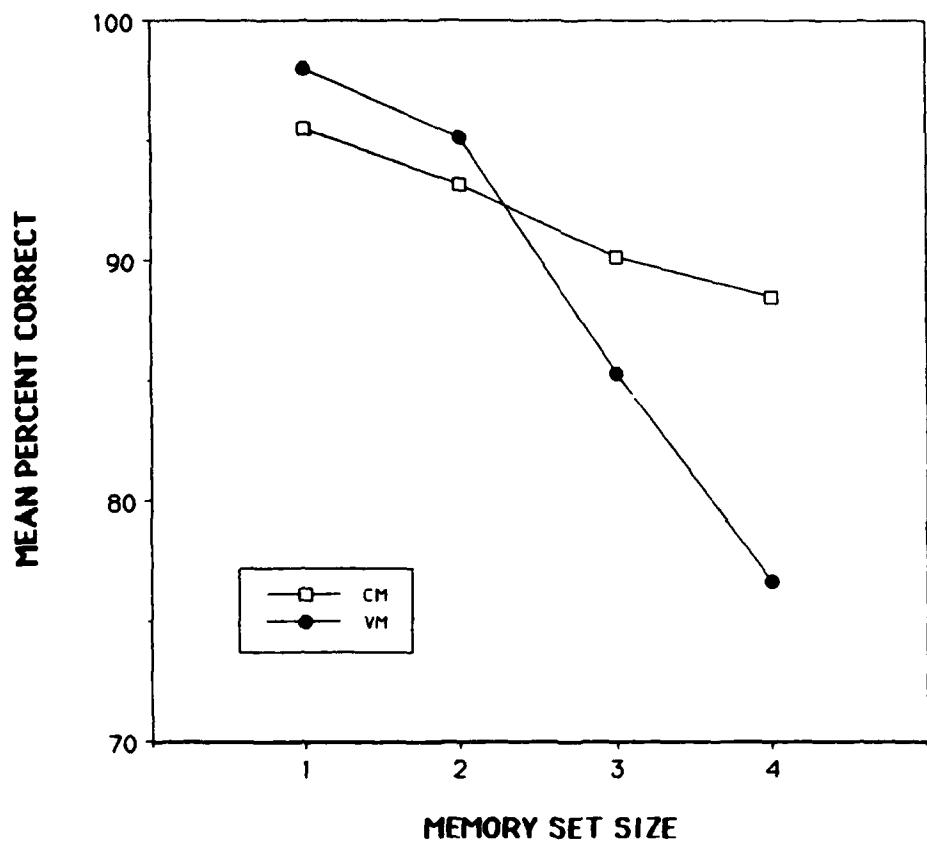


**Figure 6-7.** Mean Percent Correct as a Function of Mapping Condition, Transfer Group, and Transfer Session.

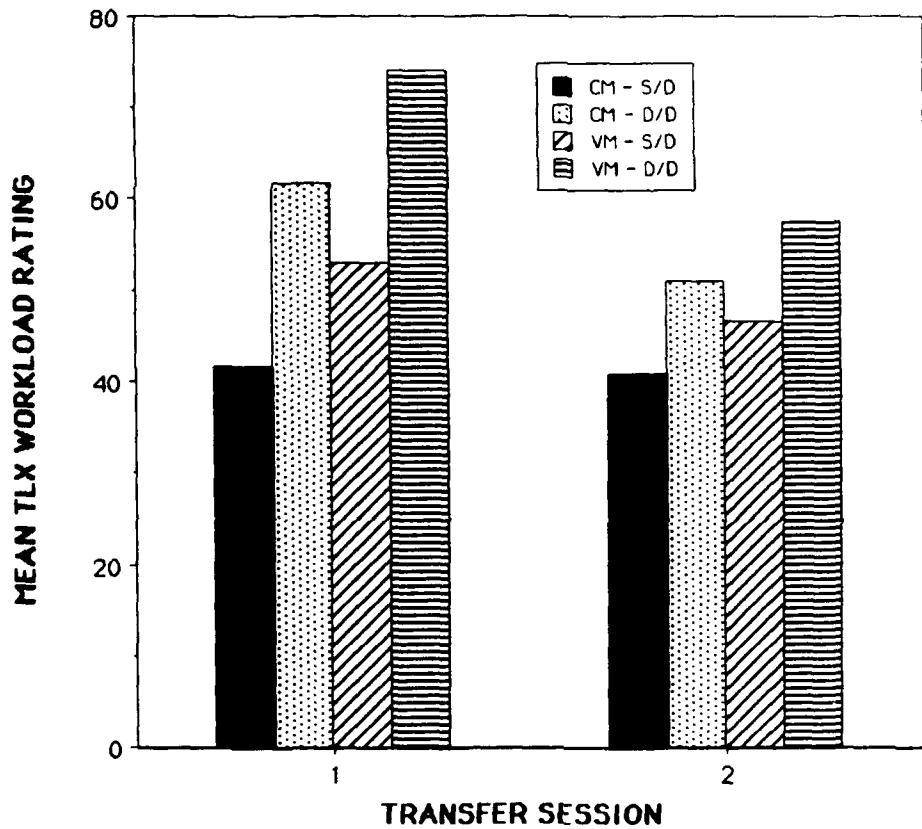
Figure 6-8 shows mean percent correct as a function of memory set size and mapping condition. As depicted in the figure, the effect of increased memory set size was more pronounced in the VM than CM condition. Once again, this type of data pattern is consistent with the presence of some level of automatic processing within the CM condition. To investigate the significant interaction of mapping condition and memory set size, tests of the memory set effect were conducted within the CM and VM conditions. These analyses showed that the effect of memory set size was significant within both the CM ( $F(3,18) = 3.68$ ,  $p < .05$ ,  $MSe = 42.89$ ) and VM ( $F(3,18) = 28.84$ ,  $p < .001$ ,  $MSe = 52.58$ ) conditions. Eta squared analyses revealed that the size of the memory set effect was greater in the VM (.828) than CM (.380) condition. Therefore, the significant interaction is attributable to the greater effect of memory set size on VM versus CM performance.

The results of the accuracy analysis are consistent with the presence of some level of automatic processing in the CM condition. The results failed to reveal any speed/accuracy tradeoff that would affect the interpretation of the previously described reaction time analyses.

Transfer Workload Analyses. Figure 6-9 shows mean NASA TLX workload ratings as a function of mapping condition, transfer group, and transfer session. The ratings depicted in Figure 6-9 are based on the overall TLX workload rating, which is the weighted combination of ratings on the six dimensions in the TLX scale. As shown in the figure, the S/D transfer group tended to exhibit lower workload ratings than the D/D group under both CM and VM conditions. This trend is more marked during the first transfer session than the second. As expected, the CM condition also tended to be associated with lower levels of workload than the VM condition.



**Figure 6-8.** Mean Percent Correct as a Function of Mapping Condition and Memory Set Size.



**Figure 6-9.** Mean TLX Workload Ratings as a Function of Mapping Condition, Transfer Group, and Transfer Session.

A 2 x 2 x 2 ANOVA was performed on the data illustrated in Figure 6-9 to investigate the effects of mapping condition, transfer group, and transfer session on mean workload ratings. This analysis demonstrated that the main effect of mapping condition ( $F(1,6) = 6.77$ ,  $p < .05$ ,  $MS_e = 95.73$ ) was significant, but the main effects of transfer group ( $F(1,6) = 0.85$ ,  $p > .05$ ,  $MS_e = 2286.40$ ) and transfer session ( $F(1,6) = 4.30$ ,  $p > .05$ ,  $MS_e = 138.40$ ) were not. None of the interactions proved to be reliable. Thus, this analysis confirms that CM workload was rated as lower than VM workload at transfer but also indicates that the trend for S/D workload to be lower than D/D workload was not reliable.

### Discussion

The results of the present experiment are important because they indicate that some benefits of automatic processing established with one set of exemplars during original training can be transferred to untrained exemplars of the same rules within a hybrid visual/memory search task. The present results extend the previous data, obtained in a memory search version of the alphanumeric rule task, to the visual/memory search paradigm used here.

These results suggest that the improvements in CM performance demonstrated during the acquisition sessions reported in Experiment 2 are at least partially attributable to learning at the rule level. This, in turn, demonstrates some level of automatic processing development at a level of consistency above that of the individual exemplars. It also suggests that Air Force training programs could be structured to take advantage of the rule-level transfer expected to occur with the complex alphanumeric materials used here.

It had also been predicted that the CM-S/D group would result in lower levels of subjective workload than either the

CM-D/D group or VM transfer groups. Although the present results indicate that the workload levels associated with the CM-S/D condition were consistently the lowest among all the conditions, this trend was not statistically reliable. However, the workload results did indicate that, overall, the workload associated with CM conditions was reliably lower than that associated with the VM conditions. Given this result, it might be true that the most pronounced workload advantages associated with the CM-S/D condition versus the CM-D/D condition were relatively short-lived. Consequently, workload ratings gathered at the completion of a 320-trial session might not reflect any initial CM-S/D advantage. This issue could be addressed in future research.

#### Experiment 7

#### Transfer of Automatic Processing with Complex Spatial Pattern Information in a Hybrid Visual/Memory Search Task

##### Purpose

The purpose of this experiment was to investigate the transfer that would result within CM and VM conditions in a visual/memory search task when previously trained static spatial patterns were rotated 90 degrees from their original orientation. The transfer of automatic processing to rotated patterns is central to eventual applications to Air Force information system operator training because such systems (Eggemeier et al., 1988) can require that spatial patterns be processed in a variety of orientations on system displays. If automatic processing, established with patterns in one orientation, cannot be transferred to the same patterns under different orientations, training programs would have to be structured to provide practice in identifying target patterns in a variety of such orientations. However, positive transfer to different orientations would suggest that training programs could be limited to providing practice in target detection under a single orientation condition.

Despite the potential importance of such transfer to training program development, there has been little work reported in the literature which permits an assessment of the effect of pattern orientation changes on performance under CM and VM conditions. In one previous study that dealt with the effects of spatial pattern rotation, Eberts and Schneider (1986) reported that rotation reduced CM performance to VM performance levels in a visual search task that required integration of successive pattern elements in order to correctly identify target patterns. Given the implications for training program design that would be associated with automatic processing of rotated patterns, it was considered important to examine such transfer with the type of spatial pattern information processed by Air Force information systems operators.

The present study was carried out using the same visual/memory search task employed in Experiment 4. In this type of search task, the subject must hold a variable number of target patterns in memory and search for them in a display that includes one or more non-target or distractor patterns. The requirement to hold a number of target patterns in memory and search a display for the presence of such targets represents an important component of the functions performed by some Air Force information systems operators. Thus, the visual/memory search task was considered ideal for this type of investigation. Display set sizes of two or four patterns and memory set sizes of two, three, or four patterns were used to investigate the joint effects of varying display and memory load on performance under CM and VM mapping conditions with rotated spatial patterns.

#### Method

Subjects. Subjects were 14 University of Dayton students who were paid \$5.00/hour. Each subject had participated in two previous experiments and had completed 4800 training trials under

either CM or VM conditions prior to this experiment. Seven of the subjects who participated in this experiment had been trained under VM conditions, and seven under CM conditions.

Apparatus. The experiment was controlled and the data were collected by Zenith Z-248 computers with extended keyboards. Stimuli were presented on Z-1490 high-resolution, thirteen-inch color monitors. Subjects responded on the keyboard.

Stimulus Materials. The same set of 16 spatial patterns used in Experiment 4 were also used in this experiment. CM subjects were assigned the same target and distractor patterns as had been trained in Experiment 4.

Procedure. Subjects performed the same type of visual/memory search task they had performed in Experiment 4. On each trial, subjects were shown a memory set of two to four spatial patterns on the computer CRT screen. Within the VM condition, the patterns comprising the memory set were selected at random from the entire stimulus pattern set; within the CM condition, the patterns were selected at random from the eight patterns designated as the target set. The memory set remained on the screen until the subject pressed the return key on the computer keyboard.

The memory set was replaced on the CRT screen with a test display that contained either two or four patterns. Each display included only one target. Therefore, there were either one or three distractor patterns present in the test display. Patterns in the test display were arranged in a quadrant. The subject was instructed to rapidly determine which pattern in the display was a member of the previously presented memory set. Subjects indicated the location of the target pattern in the test quadrant by pressing a designated key on the numeric keyboard which corresponded to the quadrant. The "four" key represented the upper left quadrant, the "five" key the upper right, the "one"

key the lower left, and the "two" key the lower right. If the subject failed to respond within 3000 ms, the display was terminated and the system recorded a miss.

Memory set varied within a 20-trial block, while display set size was blocked across sets of twenty trials. Display sets of two and four patterns alternated between 20-trial blocks.

Two dependent measures, reaction time and response accuracy, were recorded. Subjects were instructed to respond as rapidly as possible while maintaining at least a 90-percent level of accuracy.

Several types of feedback were given to the subject. After each trial, a message indicating whether the response was correct or incorrect appeared on the screen. The reaction time was given if the response was correct. At the end of each block, the percent correct and mean reaction time over the twenty trials was shown. At the completion of each phase of the experiment, the percent correct and mean reaction time for that phase were provided to the subject.

Subjects participated for one two-hour period. The experiment was divided into two phases: (a) reacquisition, and (b) transfer. During the reacquisition phase, subjects completed six 20-trial blocks each with the same set of spatial patterns trained in Experiment 4. These 120 trials constituted the reacquisition session and were intended to permit subjects to reacquire stable performance levels on the previously trained visual/memory search task. The resulting data also served as a baseline against which to compare transfer effects. During the transfer phase of the experiment, subjects completed a total of fourteen 20-trial blocks. During these trials, each of the original spatial patterns was rotated ninety degrees in a counter-clockwise direction. The purpose of this manipulation was to assess the effects of such a rotation on performance.

levels relative to the reacquisition baseline. This manipulation was the only change in the procedure from the originally trained task. To compare the results of the transfer phase directly with those of the reacquisition phase, two transfer sessions of 120 trials each were derived from the data of the first six and the last six blocks of transfer. These were designated as the first and second transfer sessions, respectively; each was comparable in trials to the reacquisition session.

Design. Four independent variables were included in the design: (a) target/distractor mapping (CM versus VM); (b) display set size (2 or 4); (c) memory set size (2, 3, or 4); and (d) reacquisition/transfer sessions (1-3).

### Results

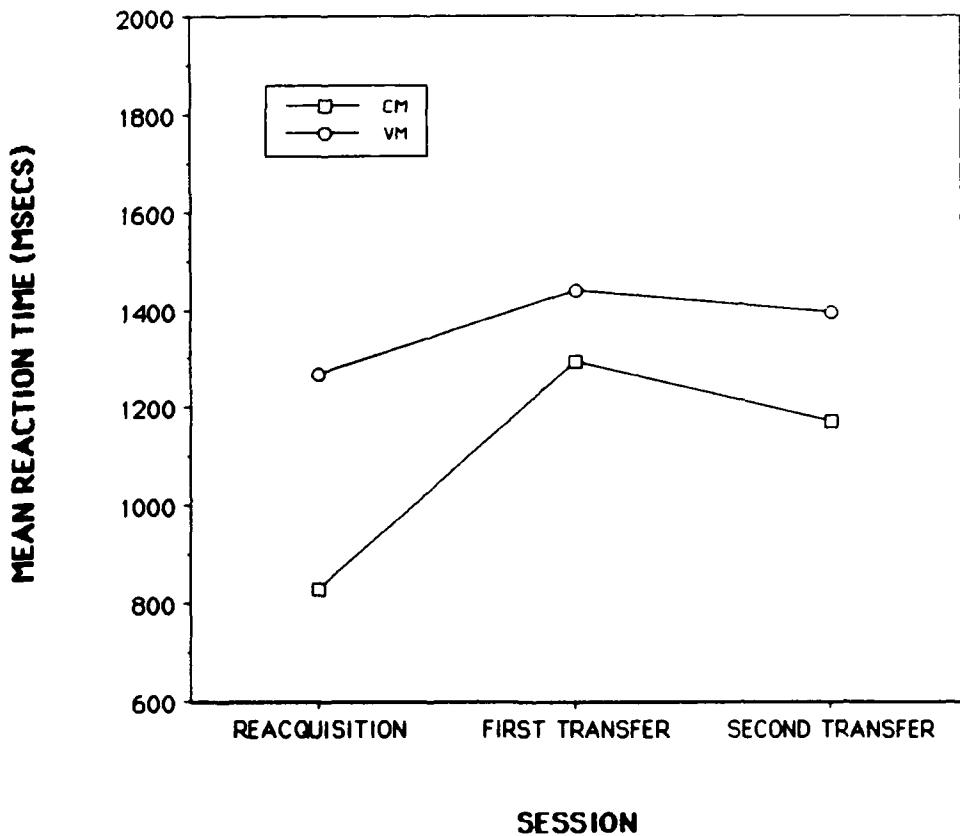
Analyses of Initial Transfer Effects. A  $2 \times 2 \times 3 \times 2$  ANOVA was performed on the reaction time data to analyze the effects of mapping condition (CM versus VM), display set size (2 or 4 patterns), memory set size (2, 3, or 4 patterns), and session (reacquisition versus first transfer). The results were used to assess the initial effects of transfer on performance. Mapping condition was a between-subjects variable, while display set size, memory set size, and sessions were within-subjects variables.

This analysis indicated that the main effects of mapping condition ( $F(1,12) = 7.83$ ,  $p < .001$ ,  $MS_e = 454647.27$ ), memory set size ( $F(2,24) = 10.44$ ,  $p < .005$ ,  $MS_e = 45149.51$ ), display set size ( $F(1,12) = 429.36$ ,  $p < .001$ ,  $MS_e = 18924.56$ ), and sessions ( $F(1,12) = 72.61$ ,  $p < .001$ ,  $MS_e = 58052.32$ ) were reliable. The interactions of mapping condition and memory set size ( $F(2,24) = 10.44$ ,  $p < .005$ ), mapping condition and sessions ( $F(1,12) = 15.25$ ,  $p < .005$ ), and display set size and sessions ( $F(1,12) = 23.20$ ,  $p < .001$ ) were also significant. No other interactions were significant.

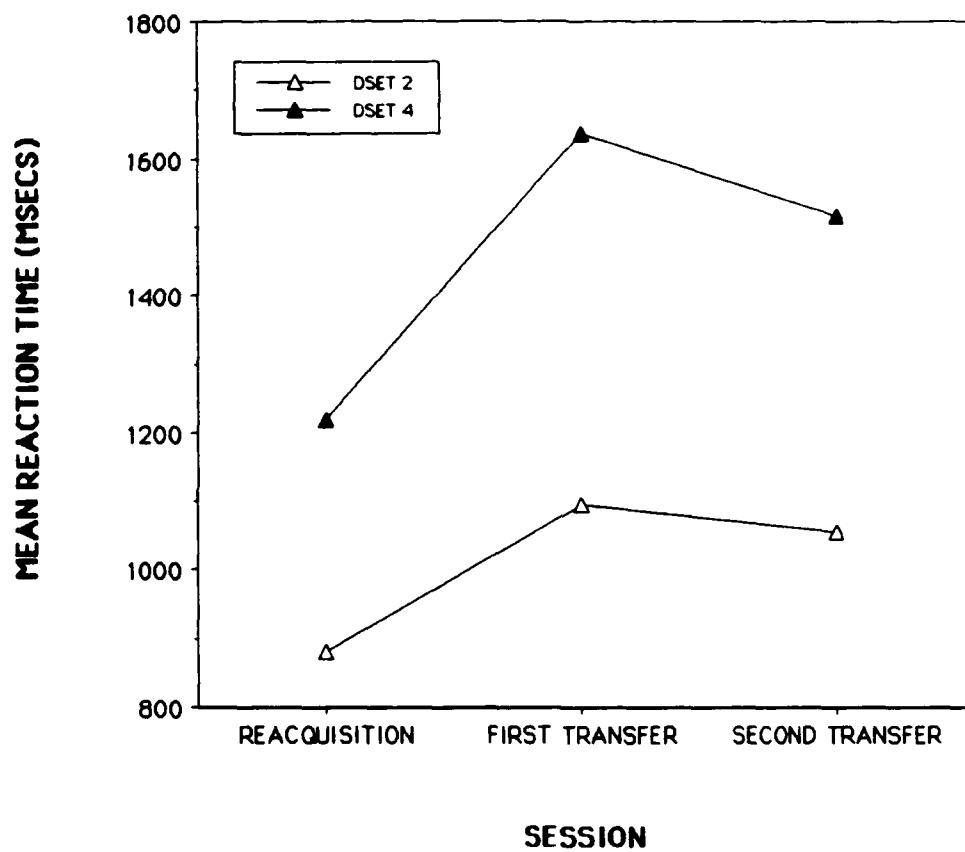
Figure 7-1 shows mean reaction time as a function of mapping condition and sessions (reacquisition baseline, first transfer, and second transfer). The reaction times are based on correct responses. As depicted in the figure, there is a trend for CM reaction times to be faster than VM reaction times during the reacquisition session, but this advantage was markedly attenuated during the first transfer session. The superiority of the CM group to the VM group during the baseline reacquisition session had been expected because all subjects had previously completed several thousand training trials under CM or VM conditions.

The significant interaction of mapping condition and sessions was evaluated through an analysis of the simple effect of mapping condition during the reacquisition and first transfer sessions. These analyses showed a significant effect of mapping condition during the baseline reacquisition session ( $F(1,12) = 17.71, p < .005, MS_e = 225784.54$ ) but failed to demonstrate an effect of mapping condition during the first transfer session ( $F(1,12) = 1.56, p > .05, MS_e = 286915.05$ ). Therefore, the effect of the pattern rotation was to eliminate the reliable CM versus VM reaction time difference that had been present during the reacquisition session.

Figure 7-2 depicts mean reaction time as a function of display set size and sessions. As seen in the figure, reaction times were slower under the display set four versus display set two condition. Reaction times were also higher under both display set two and display set four conditions at transfer relative to the reacquisition baseline. The difference in reaction time between the two display set size conditions appears to have been more pronounced during the first transfer session than during the reacquisition session. The reliable interaction of display set and sessions was investigated through an assessment of the display set effect at each session. These analyses showed that the display set effect was reliable both



**Figure 7-1. Mean Reaction Time as a Function of Mapping Condition and Test Session.**

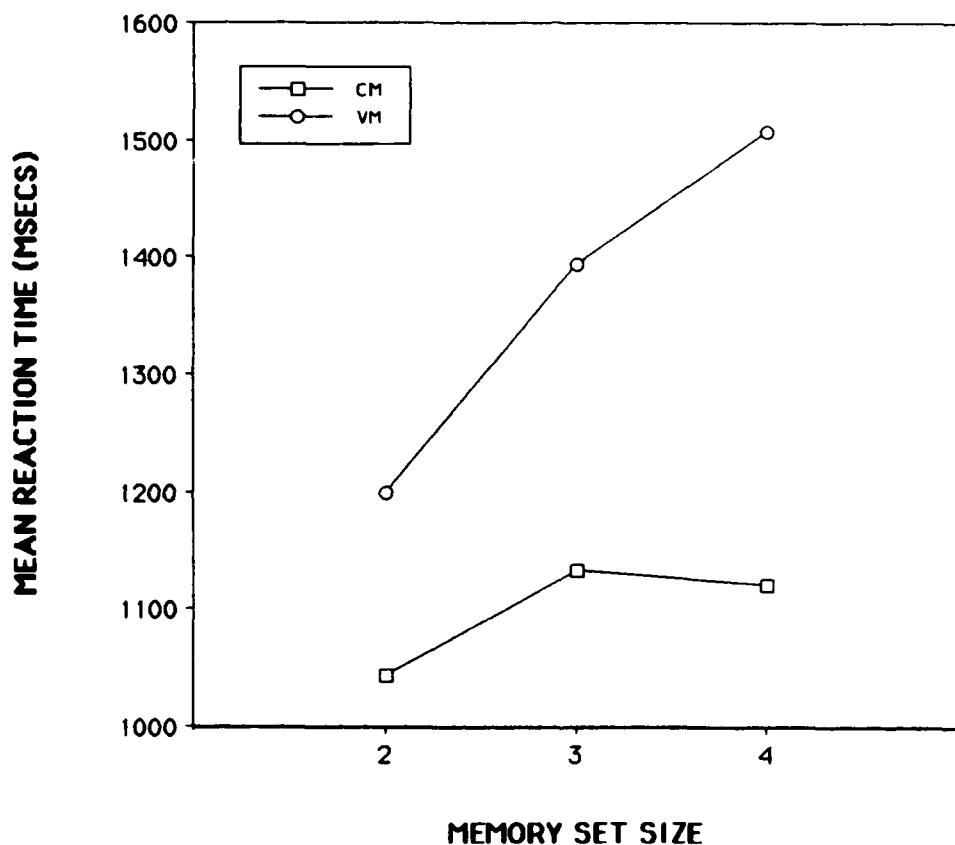


**Figure 7-2.** Mean Reaction Time as a Function of Display Set Size and Session.

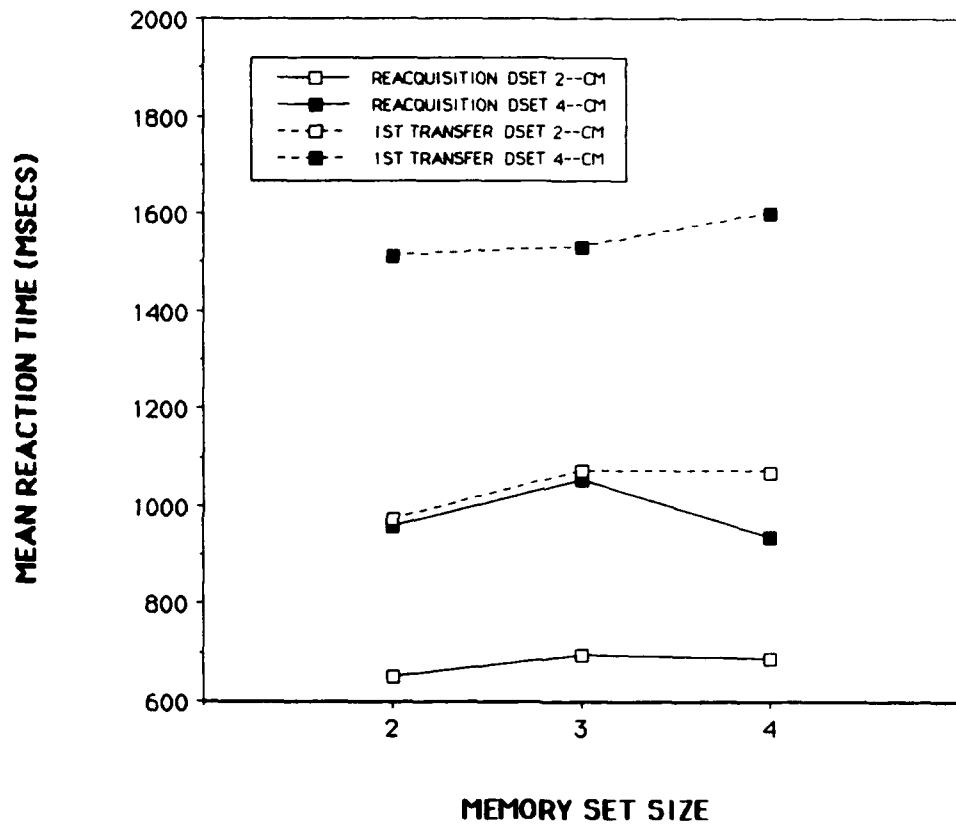
within the reacquisition session ( $F(1,12) = 135.63, p < .001$ ,  $MSe = 17715.55$ ) and the first transfer session ( $F(1,12) = 309.45, p < .001$ ,  $MSe = 19893.34$ ). Eta squared analyses of effect size showed that the display set effect was greater during the first transfer session (.962) than during the reacquisition session (.919). Therefore, one effect of pattern rotation was to increase the effect of display set size on the performance of both the CM and VM groups.

Figure 7-3 illustrates mean reaction time as a function of mapping condition and memory set size. As shown in the figure, mean reaction time showed a tendency to increase with memory set size, but this effect was much more pronounced in the VM condition than the CM condition. The differences in the memory set size effect at each mapping condition are reflected in the slopes of the functions relating reaction time to memory set size. Within the CM condition, the slope of the function was 39 ms; within the VM condition it was 154 ms. To investigate the significant interaction of mapping condition and memory set size, tests of the memory set size effect were performed within the CM and VM conditions. These analyses indicated that within the CM condition, memory set exerted no reliable effect on reaction time ( $F(2,24) = 0.70, p > .05, MSe = 45149.51$ ). However, within the VM condition, the effect of memory set was significant ( $F(2,24) = 14.52, p < .001$ ).

The attenuation of memory set size effects in the CM condition relative to the VM condition, a typical result in studies of automatic processing, would be expected during the reacquisition session. The present result, obtained across the reacquisition and first transfer sessions, indicates that any effect pattern rotation exerted on the memory search component of performance was not sufficient to eliminate the advantage of the CM condition relative to the VM condition. Figures 7-4 and 7-5 depict mean reaction time as a function of display set size, memory set size, and sessions in the CM and VM conditions,



**Figure 7-3.** Mean Reaction Time as a Function of Mapping Condition and Memory Set Size.



**Figure 7-4.** Mean Reaction Time as a Function of Display Set Size, Memory Set Size, and Session in the CM Condition.

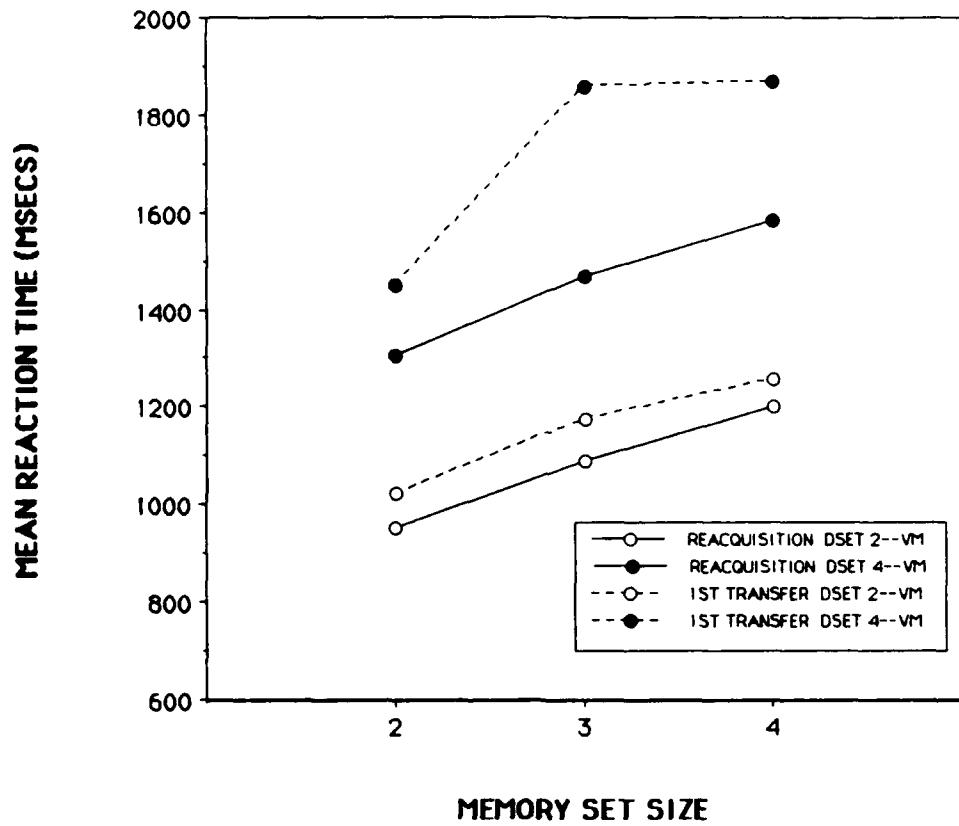
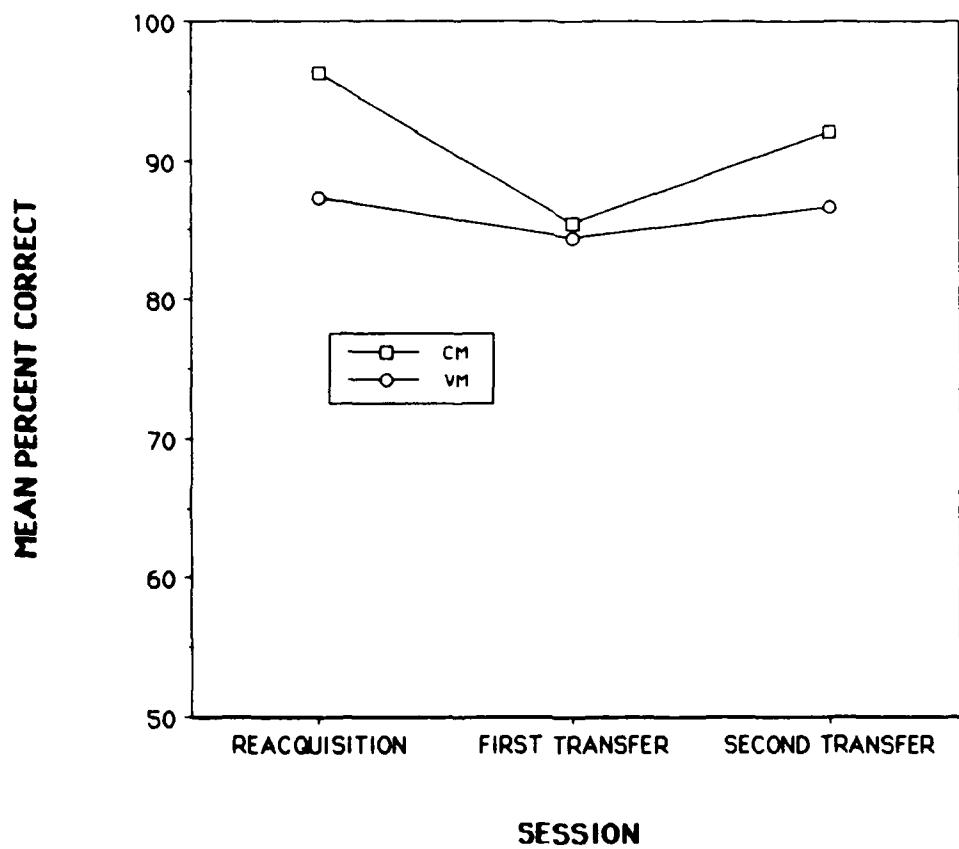


Figure 7-5. Mean Reaction Time as a Function of Display Set Size, Memory Set Size, and Session in the Variably Mapped Condition.

respectively. As illustrated in the figures, the rotation of patterns tended to have the greatest influence on the display set size effect within the CM condition, while the CM memory set size effect remained relatively stable from the reacquisition session to the first transfer session. Increases in the display set size effect from the baseline reacquisition session to the transfer session within the VM condition tended to be less pronounced than in the CM condition; this difference appears to have contributed to the elimination of the mapping condition main effect at transfer.

In addition to reaction time analyses, the effects of pattern rotation on performance accuracy were assessed. Figure 7-6 shows mean percent correct as a function of mapping condition and test session (reacquisition baseline, first transfer, and second transfer). As illustrated in the figure, the magnitude of differences between CM and VM groups that were present at reacquisition was attenuated during transfer, particularly during the first transfer session.

A  $2 \times 2 \times 3 \times 2$  ANOVA, comparable to the reaction time analysis, was performed on the percent correct data to analyze the effects of mapping condition (CM versus VM), memory set size (2, 3, or 4 patterns), display set size (2 or 4 patterns) and test session (reacquisition versus first transfer). This analysis indicated that the main effects of session ( $F(1,12) = 24.38$ ,  $p < .001$ ,  $MS_e = 82.72$ ), memory set size ( $F(2,24) = 19.74$ ,  $p < .001$ ,  $MS_e = 49.66$ ), and display set size ( $F(1,12) = 12.79$ ,  $p < .005$ ,  $MS_e = 133.73$ ) were reliable. The main effect of mapping condition ( $F(1,12) = 1.18$ ,  $p > .05$ ,  $MS_e = 916.69$ ) was not significant. The basis of the reliable sessions effect is illustrated in Figure 7-6. This figure shows that overall levels of accuracy were lower during the initial transfer session than during the reacquisition session.

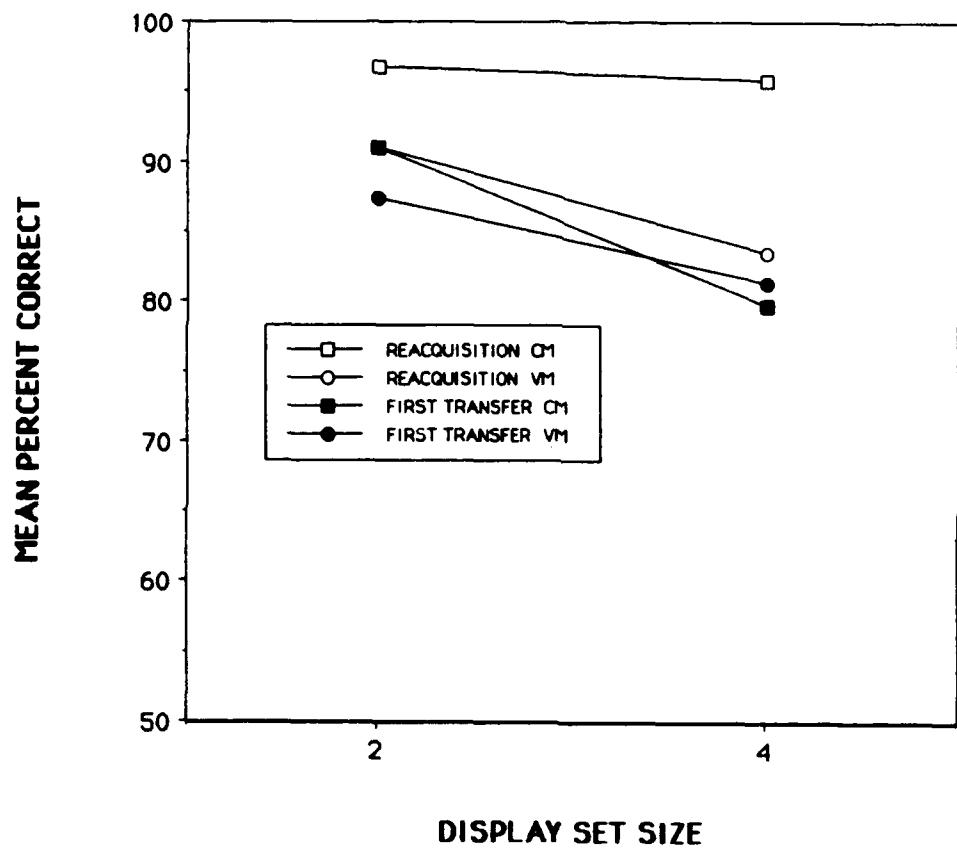


**Figure 7-6.** Mean Percent Correct as a Function of Mapping Condition and Test Session.

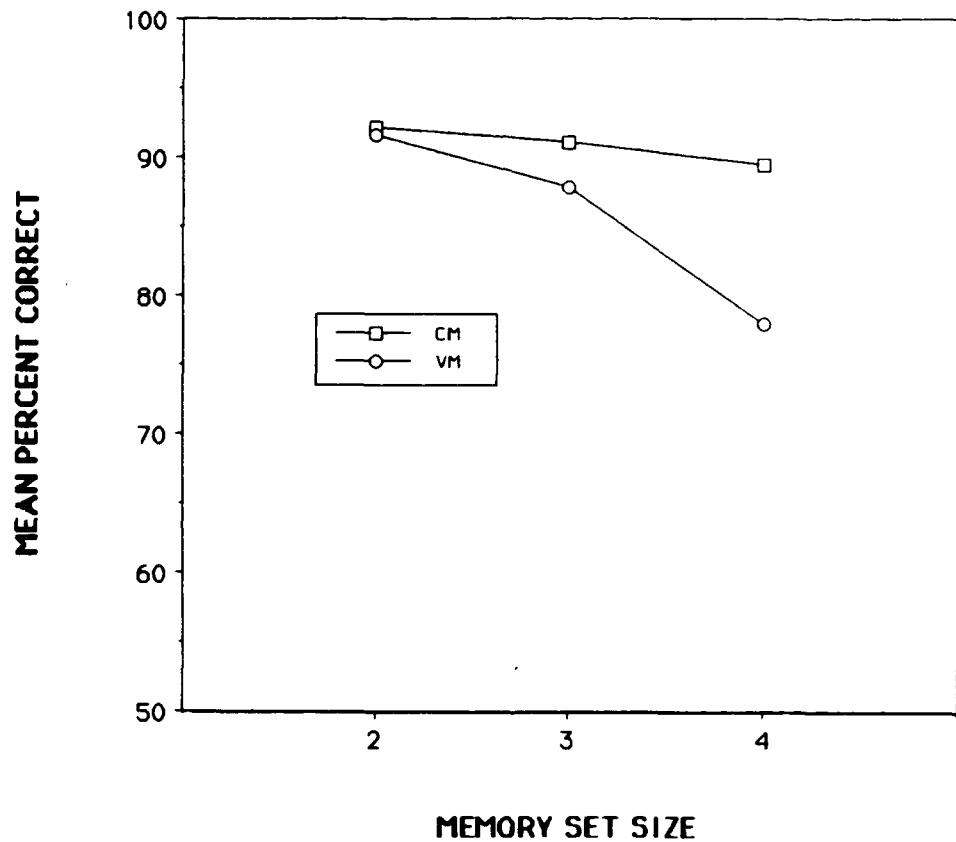
The interactions of memory set size and display set size ( $F(2,24) = 5.94$ ,  $p < .01$ ,  $MS_e = 46.90$ ), mapping condition and memory set size ( $F(2,24) = 9.17$ ,  $p < .005$ ), mapping condition and session ( $F(1,12) = 8.22$ ,  $p < .005$ ), and the three-way interaction of mapping condition, session, and display set size ( $F(1,12) = 6.36$ ,  $p < .001$ ,  $MS_e = 55.76$ ) also were reliable.

Figure 7-7 illustrates mean percent correct as a function of mapping condition, display set size, and session. As shown in the figure, display set size had a more pronounced effect on VM than CM performance during the reacquisition session, but this difference was attenuated during the first transfer session. Tests of the effects of display set size and session were conducted within the CM and VM conditions to investigate the reliable three-way interaction of mapping condition, display set size, and sessions. These analyses showed that, within the VM condition, the effect of display set size ( $F(1,12) = 7.08$ ,  $p < .05$ ,  $MS_e = 133.73$ ) was significant, but neither the effect of sessions ( $F(1,12) = 2.14$ ,  $p > .05$ ,  $MS_e = 82.72$ ) nor the interaction of display set size and sessions ( $F(1,12) = 0.17$ ,  $p > .05$ ,  $MS_e = 55.76$ ) were reliable. However, within the CM condition, the main effects of both display set size ( $F(1,12) = 5.74$ ,  $p < .05$ ) and sessions ( $F(1,12) = 30.45$ ,  $p < .001$ ) were reliable, as was the interaction of sessions and display set size ( $F(1,12) = 9.96$ ,  $p < .01$ ). These results indicate that, while the effect of display set size did not differ reliably as a function of sessions within the VM condition, display set effects were more pronounced during the first transfer session as opposed to the reacquisition session within the CM condition.

Figure 7-8 depicts mean percent correct as a function of mapping condition and memory set size across the reacquisition and first transfer sessions. The figure illustrates that memory set size affected VM performance more substantially than CM performance, particularly at the higher memory set sizes. To investigate the reliable interaction of mapping condition and



**Figure 7-7.** Mean Percent Correct as a Function of Mapping Condition, Display Set Size, and Session.

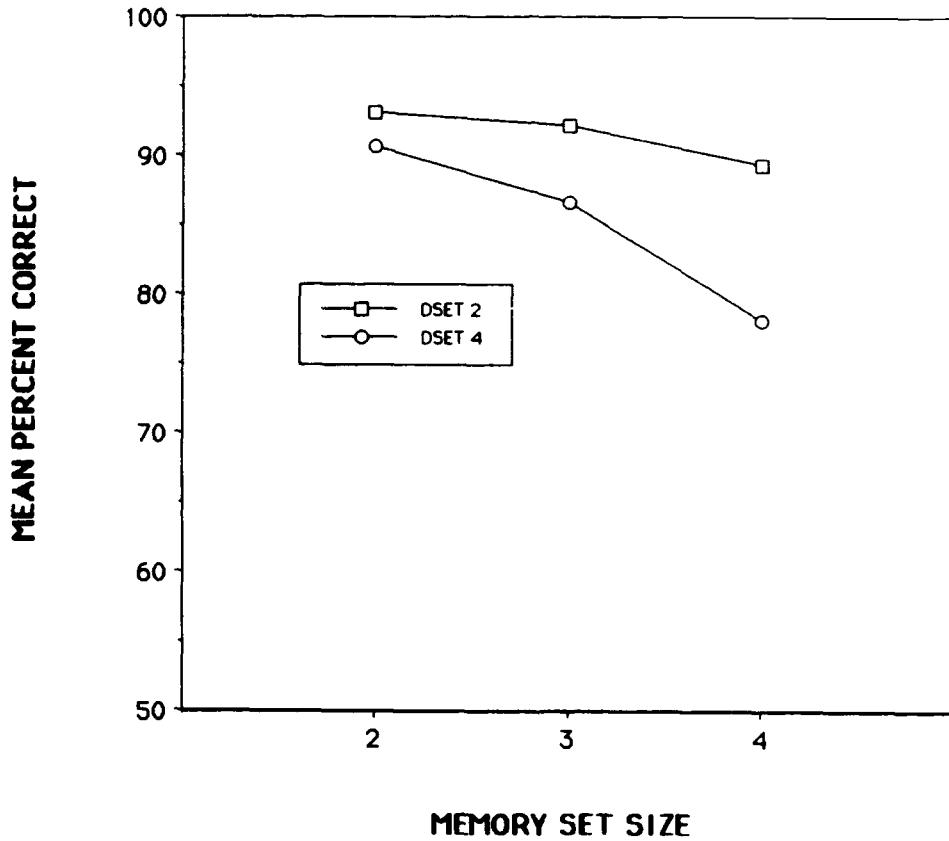


**Figure 7-8.** Mean Percent Correct as a Function of Mapping Condition and Memory Set Size.

memory set, tests of the memory set size effect were performed within the CM and VM conditions. These analyses indicated that, within the CM condition, memory set size did not reliably affect performance accuracy ( $F(2,24) = 1.02$ ,  $p > .05$ ,  $MS_e = 49.66$ ); within the VM condition, there was a significant effect of memory set size on performance ( $F(2,24) = 27.89$ ,  $p < .001$ ). As in the reaction time analysis, the greater attenuation of memory set size effects within the CM versus the VM condition is a characteristic of automatic processing within the former condition. Once again, the presence of this effect across the reacquisition and first transfer sessions indicates that the pattern rotation effect was not sufficient to reliably disrupt this aspect of automatic processing.

The effects of memory set and display set across the reacquisition and first transfer sessions are shown in Figure 7-9. In general, the memory set size effect was more pronounced at display set size four than at display set size two. Analyses conducted to investigate the reliable interaction of display set and memory set confirmed these trends. These analyses indicated that the memory set size effect was not reliable at display set size two ( $F(2,24) = 3.21$ ,  $p > .05$ ,  $MS_e = 33.68$ ); however, there was a significant memory set size effect at display set size four ( $F(2,24) = 18.30$ ,  $p < .001$ ).

Analyses of Final Transfer Effects. The initial transfer analyses, reported above, indicated that the effect of pattern rotation during the first transfer session was the elimination of reliable CM-VM performance differences present during the reacquisition session. However, the previous analyses did not address whether CM-VM performance differences would be re-established after a minimal period of retraining. To address that issue, analyses were performed to examine the effects of mapping condition, memory set, and display set within the first and second transfer sessions. The reaction time data for the



**Figure 7-9.** Mean Percent Correct as a Function of Memory Set Size and Display Set Size.

first and second transfer sessions were analyzed in a  $2 \times 3 \times 2 \times 2$  ANOVA that included the variables noted above.

This analysis showed that the main effects of memory set size ( $F(2,24) = 13.76, p <.005, MS_e = 52552.66$ ), display set size ( $F(1,12) = 153.31, p <.001, MS_e = 68997.26$ ), and sessions ( $F(1,12) = 14.17, p <.001, MS_e = 58052.32$ ) were reliable. The main effect of mapping condition, however, was not significant ( $F(1,12) = 3.30, p >.05, MS_e = 430814.67$ ). The four-way interaction of mapping condition, sessions, memory set, and display set was significant ( $F(2,24) = 8.48, p <.005, MS_e = 10428.22$ ), but all the other interactions proved to be nonsignificant.

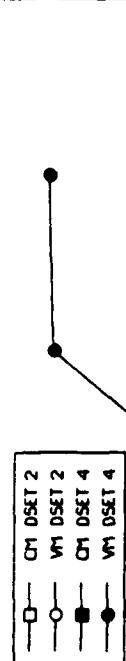
Figure 7-10 depicts mean reaction time as a function of mapping condition, memory set size, and display set size in the first and second transfer sessions. As illustrated in the figure, display set size had a rather marked effect on performance under both mapping conditions in both sessions, but the memory set size effect within the display set size four condition in the VM versus CM condition varied somewhat as a function of session. Within the second session, the discrepancy in performance between the VM and CM groups at the highest memory set size within the display set size four condition appears somewhat more pronounced than the comparable difference within the first transfer session.

To investigate the reliable four-way interaction, the effects of mapping condition, memory set, and display set were analyzed within the first and second transfer sessions. These analyses indicated that, as expected within the first transfer session, there was no main effect of mapping condition ( $F(1,12) = 1.56, p >.05, MS_e = 286915.05$ ). However, the main effects of memory set ( $F(2,24) = 10.46, p <.005, MS_e = 32704.16$ ), display set ( $F(1,12) = 309.45, p <.001, MS_e = 17893.34$ ), and the interaction of mapping condition and memory set

FIRST TRANSFER SESSION

2000  
1800  
1600  
1400  
1200  
1000  
800

MEAN REACTION TIME (MSECS)

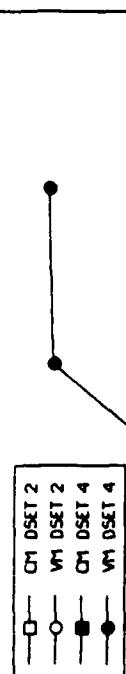


MEMORY SET SIZE

SECOND TRANSFER SESSION

2000  
1800  
1600  
1400  
1200  
1000  
800

MEAN REACTION TIME (MSECS)



MEMORY SET SIZE

Figure 7-10. Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Display Set Size.

( $F(2,24) = 3.75, p < .05$ ) were reliable. The interaction reflects the relatively small effect of memory set within the CM condition relative to the VM condition. None of the other interactions, including the three-way interaction of mapping condition, memory set, and display set ( $F(2,24) = 2.25, p > .05, MS_e = 22750.76$ ) were significant. Eta squared analyses indicated that the effect size associated with the three-way interaction was .158.

Within the second transfer session, the analyses showed that the main effect of mapping condition ( $F(1,12) = 6.32, p < .05, MS_e = 163598.38$ ) was reliable, as were the main effects of memory set size ( $F(2,24) = 11.30, p < .001, MS_e = 3430.92$ ) and display set size ( $F(1,12) = 51.76, p < .001, MS_e = 86672.56$ ). None of the interactions proved to be significant, although the  $F$  value associated with the interaction of mapping condition, memory set, and display set ( $F(2,24) = 2.81, p < .10, MS_e = 19501.45$ ) approached the value required for significance. Eta squared analyses indicated that the effect size associated with this interaction was .190. Thus, this analysis indicated that during the second transfer session, reliable differences between CM and VM performance had been re-established after relatively modest amounts of additional training. The basis of this effect can be observed in Figure 7-1, which shows that mean reaction time was reduced in the second transfer session relative to the first within the CM condition. The reliable four-way interaction obtained in the overall ANOVA is attributable to the stronger effect of the three-way interaction of mapping condition, memory set size, and display set size within the second transfer session relative to the first.

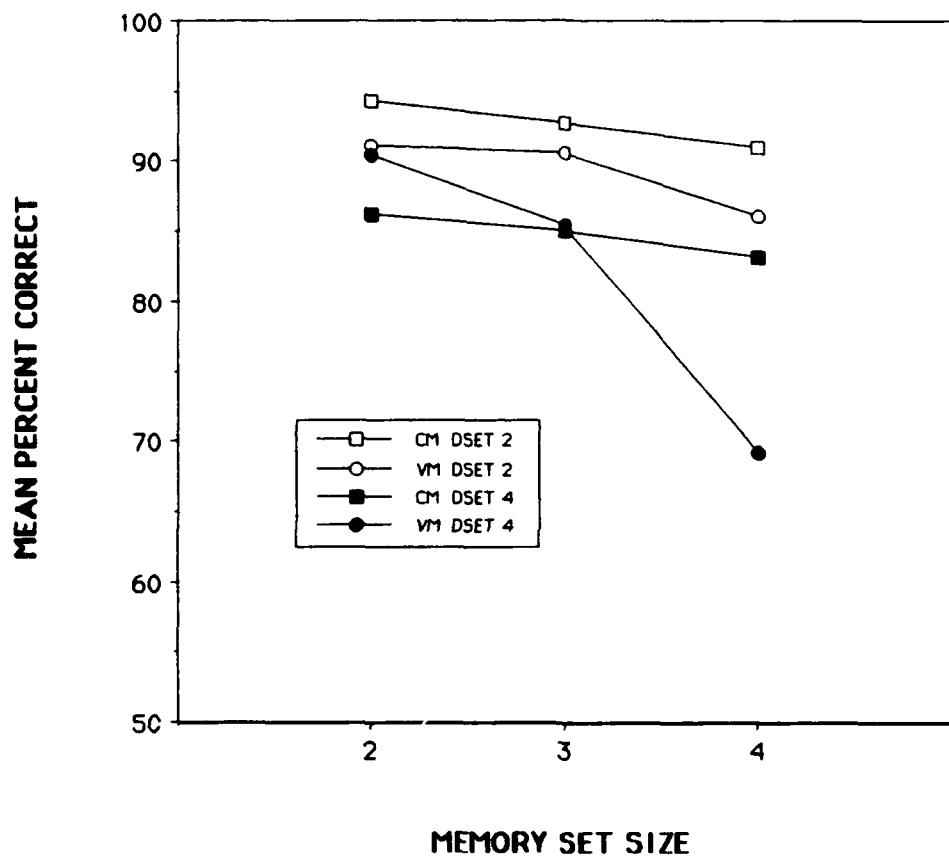
A  $2 \times 2 \times 3 \times 2$  ANOVA, comparable to the reaction time analysis, was performed on the percent correct data to analyze the effects of mapping condition (CM versus VM), memory set size (2, 3, or 4 patterns), display set size (2 or 4 patterns) and session (first transfer versus second transfer) on performance. This analysis showed that the main effects of session

( $F(1,12) = 14.57$ ,  $p < .005$ ,  $MS_e = 57.45$ ), memory set size ( $F(2,24) = 16.86$ ,  $p < .001$ ,  $MS_e = 59.97$ ), and display set size ( $F(1,12) = 18.33$ ,  $p < .005$ ,  $MS_e = 136.80$ ) were significant, but the main effect of mapping condition ( $F(1,12) = 0.41$ ,  $p > .05$ ,  $MS_e = 1105.83$ ) was not. As illustrated in Figure 7-6, percent correct performance improved from the first transfer session to the second; this improvement is reflected in the main effect of the sessions in the analysis.

The interactions of memory set size and sessions ( $F(2,24) = 3.52$ ,  $p < .05$ ,  $MS_e = 42.15$ ), mapping condition and memory set size ( $F(2,24) = 6.75$ ,  $p < .01$ ), mapping condition and sessions ( $F(1,12) = 8.22$ ,  $p < .005$ ), and memory set size and display set size ( $F(2,24) = 3.52$ ,  $p < .05$ ,  $MS_e = 66.05$ ) were also reliable. In addition, the three-way interactions of mapping condition, sessions, and display set size ( $F(1,12) = 5.42$ ,  $p < .05$ ,  $MS_e = 47.03$ ) and mapping condition, memory set size, and display set size ( $F(2,24) = 3.82$ ,  $p < .05$ ) were significant.

Figure 7-11 illustrates the effect of mapping condition, memory set size, and display set size on mean percent correct during the two transfer sessions. As shown in the figure, memory set size had little effect on performance, except under the VM display set size four condition. The tendency for memory set size to have its most pronounced effect on performance under the higher display load within VM conditions is consistent with expectations. This tendency has been demonstrated in previous experiments in this series.

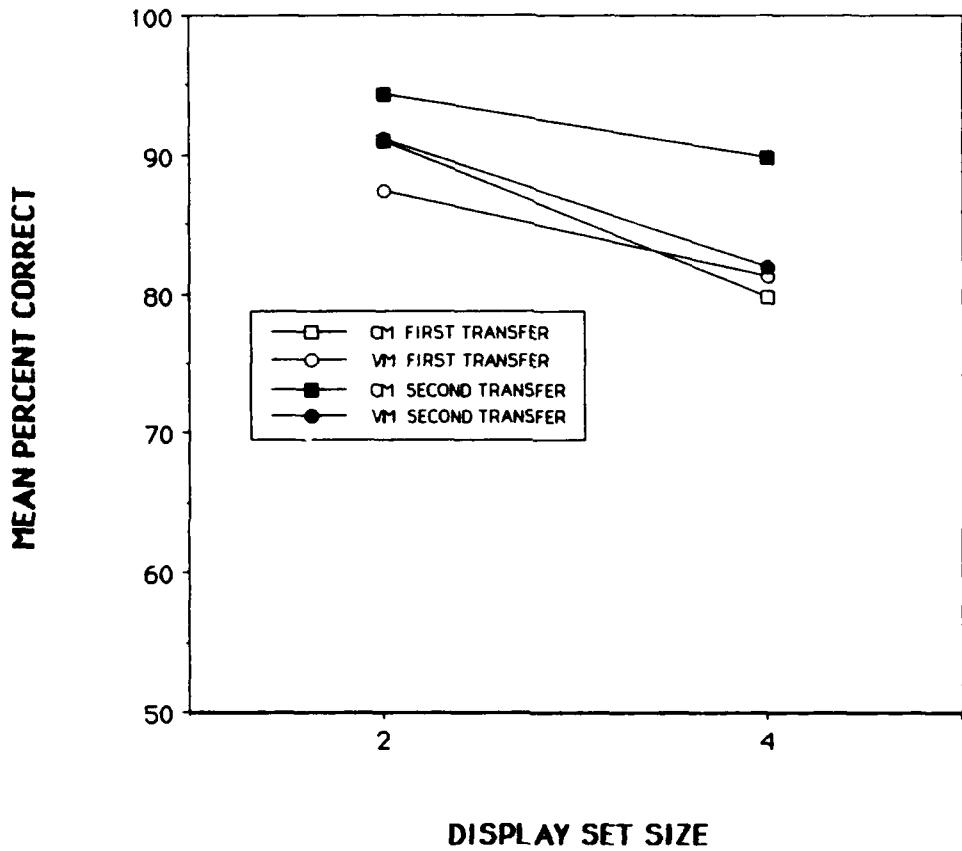
The three-way interaction of mapping condition, memory set size, and display set size was investigated through analyses of memory set size and display set size effects within the CM and VM conditions. These analyses showed that within the CM condition, the effect of display set size ( $F(1,12) = 9.42$ ,  $p < .05$ ,



**Figure 7-11.** Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Display Set Size.

$MS_e = 136.80$ ) was significant, but neither the effect of memory set size ( $F(2,24) = 1.21, p > .05, MS_e = 59.97$ ) nor the interaction of memory set and display set size ( $F(2,24) = 0.01, p > .05, MS_e = 66.05$ ) were reliable. Within the VM condition, the effects of display set size ( $F(1,12) = 8.91, p < .05$ ), memory set size ( $F(2,24) = 22.39, p < .001$ ), and their interaction ( $F(2,24) = 7.34, p < .005$ ) all proved to be significant. This interaction reflects the previously noted stronger effect of memory set at display set size four relative to display set size two.

Figure 7-12 depicts mean percent correct as a function of mapping condition, display set size, and transfer session. As illustrated in the figure, the CM and VM groups demonstrated very similar effects of display set size during the first transfer session. However, during the second transfer session, there was a tendency for the display set size effect to be attenuated in the CM group relative to the VM group. Analyses of the effects of display set size and mapping condition were conducted at each session to investigate the reliable three-way interaction of mapping condition, display set size, and session. Within the first transfer session, there was a main effect of display set size ( $F(1,12) = 13.02, p < .005, MS_e = 119.71$ ), but the main effects of mapping condition ( $F(1,12) = 0.04, p > .05, MS_e = 626.90$ ) and their interaction ( $F(1,12) = 1.16, p > .05$ ) were nonsignificant. Within the second transfer session, there was a significant effect of display set size ( $F(1,12) = 15.31, p < .005, MS_e = 64.05$ ), but the main effects of mapping condition ( $F(1,12) = 1.18, p > .05, MS_e = 536.38$ ) and the interaction of mapping condition and display set ( $F(1,12) = 1.82 p > .05$ ) were not reliable. Eta squared analyses indicated that the interaction effect was larger during the second transfer session (.132) than in the first (.088). This reflected the tendency toward attenuation of the display set size effect in the CM versus the VM condition during the second transfer session.



**Figure 7-12.** Mean Percent Correct as a Function of Mapping Condition, Display Set Size, and Session.

The two-way interaction of memory set size and transfer sessions was also significant in the overall ANOVA. Figure 7-13 illustrates mean percent correct as a function of memory set size and transfer sessions. As shown in the figure, memory set size had a more pronounced effect on performance during the first transfer session than during the second. Tests of the memory set effect at each transfer session indicated that the effect was reliable within both Session 1 ( $F(2,24) = 13.70, p < .001$ ,  $MS_e = 66.68$ ) and Session 2 ( $F(2,24) = 6.94, p < .001$ ,  $MS_e = 35.44$ ). As anticipated from the pattern of the data in Figure 7-13, the effect of memory set, as indexed by Eta squared analyses, was larger within Session 1 (.533) than within Session 2 (.367). Therefore, an effect of the training provided during the transfer sessions was attenuation of the memory set size effect on performance accuracy.

### Discussion

The results of the initial transfer analysis indicated that the introduction of the 90-degree pattern rotation eliminated reliable reaction time differences between the CM and VM conditions during the first transfer session. This effect is consistent with the data of Eberts and Schneider (1986) who also reported an elimination of CM-VM differences as a consequence of spatial pattern rotation in a visual search task. The results have important implications for the design of training programs intended to establish automatic processing with spatial pattern information. The data indicate that initial CM transfer performance to rotated patterns will not exhibit the speed advantages typically associated with automatic processing. Therefore, some training with rotated patterns would be desirable if initial transfer is critical to operator performance.

The present data provide some information regarding the probable locus of the rotation effect. The attenuation of the memory set size effect in the CM condition relative to the VM

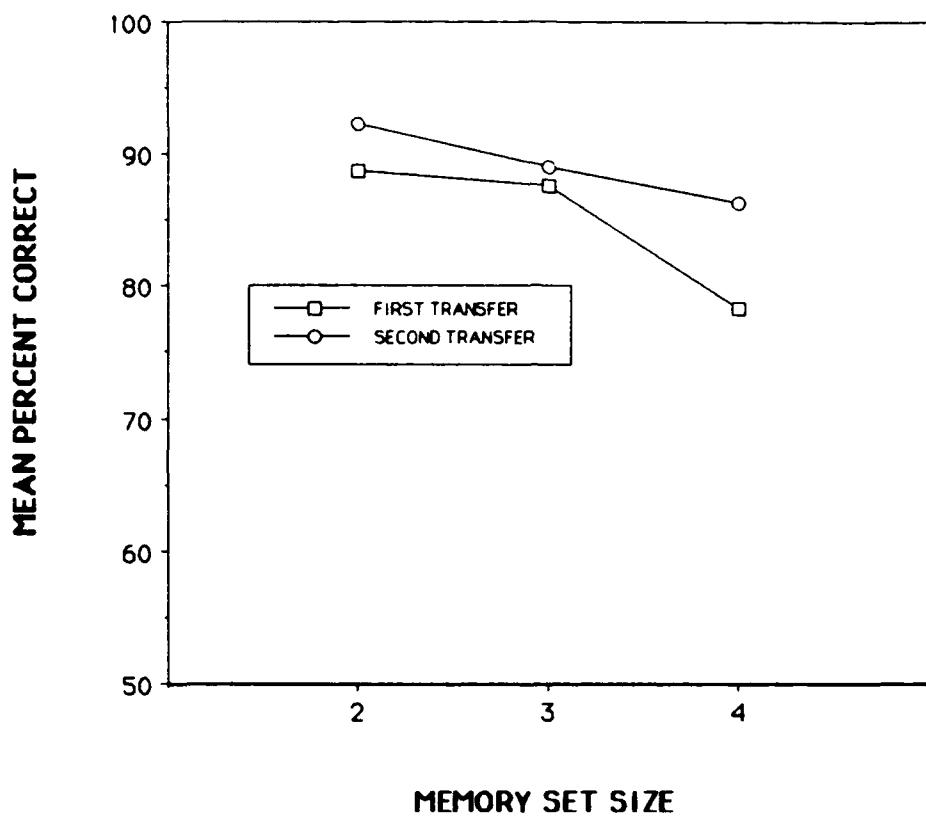


Figure 7-13. Mean Percent Correct as a Function of Memory Set Size and Session.

condition continued to be reliable across the reacquisition baseline and the first transfer sessions, thereby indicating that the pattern rotation effect was not of sufficient magnitude to eliminate this characteristic of automatic processing. Although the three-way interaction of mapping condition, display set, and session was not reliable, there was some tendency for the display set size effect to be more marked within the CM condition versus the VM condition at transfer. This trend, coupled with the continued attenuation of memory set size effects in the CM relative to the VM condition, suggests that pattern rotation exerted an effect on the visual search component of the CM task. In contrast to the reaction time analysis, the accuracy analysis demonstrated a significant three-way interaction of mapping condition, display set size, and sessions. This interaction reflected an increase in the display set size effect within the CM condition in the first transfer session relative to the reacquisition training baseline; thus, the result is consistent with the hypothesized locus of the rotation effect on CM performance.

The results of the analysis of the two transfer sessions indicated that, at the second transfer session, a reliable difference between CM and VM reaction time performance had been re-established. Accuracy analyses also demonstrated some trend for display set effect attenuation under CM conditions within the second transfer session. These results indicate that some pattern rotation effects on automatic processing might be short-lived. The results further suggest that extensive training programs under different pattern rotations might not be required to re-establish some advantages of CM processing. It is important to note, of course, that the present subjects were not required to process rotated and non-rotated patterns within the same session. Such session-concurrent processing would represent a requirement in operational systems and should be evaluated in future research. It is quite possible, for example, that some negative transfer from rotated to non-rotated patterns would

occur; such possibilities should be evaluated in future work. Future research should also consider a number of other issues not addressed by the present experiment, such as the amount of training required to permit the processing of rotated patterns at the same levels achieved at the conclusion of training with non-rotated patterns.

#### Experiment 8

#### Transfer of Training in a Memory Search Task Requiring the Processing of Spatial Pattern Information

##### Purpose

The purpose of this experiment was to investigate performance levels that could be achieved under several transfer conditions in a memory search task that required the processing of static spatial pattern information. This experiment examined the transfer of automatic processing. Therefore, all training and transfer sessions were conducted under CM conditions.

The major issue investigated was the transfer of target and distractor items subsequent to some level of automatic processing development within a memory search paradigm. Strength theory approaches (e.g., Dumais, 1979; Schneider and Detweiler, 1988) to automatic processing suggest that, within paradigms with a visual search component, automatic processing development is at least partially attributable to a strengthening of the attentional response to target stimuli, and a weakening of the response to non-target or distractor stimuli. Complementary strengthening of the response to targets and weakening of the response to non-targets would provide a basis to account for the efficiency that characterizes automatic processing of targets against a background of distractors.

As noted by Fisk et al. (1990, 1991), such an approach to automatic processing is not only of theoretical interest; it also

has important practical implications for applications of automatic processing to operator training. It is possible, for instance, for targets that have received extensive CM training with one set of distractors under one type of operational condition to remain targets in a second operational setting that incorporates a totally different set of previously untrained distractors. This would constitute a target transfer condition. Likewise, distractor items that have received previous CM training with one set of targets could continue as distractors under a different condition that requires the processing of a new set of targets. This would represent a distractor transfer condition. A third possible scenario concerns actual role reversal in which previously trained targets become distractors and previously trained distractors become targets within the same scenario. This would constitute a complete reversal condition.

Based on the assumption that targets have been strengthened and distractors weakened as a result of previous training, certain predictions regarding the transfer that would be obtained under visual search within each noted condition can be made. Because of the strength that would accrue to previously trained targets under target transfer conditions, positive transfer relative to a new CM condition that incorporates both new targets and new distractors would be expected. Due to the weakening of distractors, the distractor transfer condition would also be expected to yield positive transfer relative to a new CM condition. Finally, negative transfer would be expected to result from the complete reversal conditions, due to the joint necessity to respond to previously weakened items and withhold a response from previously strengthened items. A number of investigators have reported results that are consistent with the predictions of strength theory. Fisk et al. (1990, 1991), for example, have reported that target reversal conditions, in which previous targets serve as distractors, lead to disruptions of performance relative to new CM controls during visual search for semantic materials.

The purpose of the present experiment was to investigate the transfer that would be obtained within a memory search paradigm with targets and distractors that represented the type of spatial pattern information processed by C<sup>2</sup> systems operators. Much of the previous work (e.g., Fisk et al., 1990, 1991; Shiffrin and Schneider, 1977) with target and distractor transfer/reversal has been performed with alphanumeric or semantic category information. Therefore, it was considered important to extend prior work to the type of spatial pattern information processed within C<sup>2</sup> systems. Previous work with target and distractor transfer/reversal has also centered on paradigms that incorporate a visual search component; a second objective of the present study was to investigate such transfer within the context of a memory search paradigm. The memory search task was chosen for this work because it represents an important component of many C<sup>2</sup> operator functions that require rapid discrimination of target and distractor items. However, because memory search paradigms present only a single probe item that requires a positive response to targets and a negative response to distractors, the degree of learning that might be associated with distractors within this type of search task was questionable.

It was assumed that target learning would occur within the memory search paradigm. Therefore, positive transfer was expected within a condition that involved the processing of previously trained targets and untrained distractors in comparison with a new CM condition that required the processing of previously untrained targets and distractors. If some distractor learning also occurred within a memory search paradigm, positive transfer relative to a new CM control would be expected in a distractor transfer condition that involved untrained targets and previously trained distractors. If no such learning occurred, the distractor transfer condition would be expected to yield results equivalent to the new CM control. Likewise, if both target and distractor learning occurred within

the memory search paradigm, it was assumed that a complete or full reversal condition, which required negative responses to former targets and positive responses to former distractors, should result in at least initial performance disruption relative to a new CM condition. Initial negative transfer might also occur in this condition if only target learning took place during training because a partial or target reversal condition has been demonstrated (e.g., Fisk et al., 1990, 1991) to lead to negative transfer in tasks with a visual search component.

Eggemeier et al. (1990, 1991) reported evidence of automatic processing development in a memory search paradigm with static spatial patterns intended to represent target movement within Air Force C<sup>2</sup> systems. These systems require the operator to identify spatial patterns associated with the movement of targets or events (e.g., aircraft, weather phenomena) which are represented by dot patterns that move progressively across the system display with elapsed time. The present experiment built upon the previous memory search work with such patterns and included both acquisition and transfer phases. During acquisition, patterns similar to those employed by Eggemeier et al. (1990, 1991) were extensively trained within a memory search paradigm. Subsequent to training, subjects were transferred to one of four conditions: (a) target transfer (TT), in which previously trained target patterns were paired with untrained distractor patterns; (b) distractor transfer (DT), in which previously trained distractors were paired with untrained targets; (c) complete reversal transfer (CR), in which the role of previously trained targets and distractors were reversed; and (d) new CM transfer (NCM), in which both untrained targets and untrained distractors were introduced. The last condition is a control which was used to evaluate transfer effects in the preceding three conditions.

## Method

Subjects. Subjects were 16 University of Dayton students, who were paid \$4.00/hour. In addition, subjects were awarded a bonus payment of \$1.00/hour for appearing on time for each scheduled experimental session.

Apparatus. The experiment was controlled with a Zenith Data Systems 248 computer. The computer was programmed to present stimuli, control the timing of stimulus presentation, and collect subject responses. Subjects viewed spatial pattern stimuli on a Zenith ZCM-1490 high-resolution, thirteen-inch color monitor. Responses were made on the arrow keys located in the lower right-hand corner of a standard expanded IBM-compatible keyboard. Auditory feedback concerning performance levels was presented to subjects through the speakers on the Zenith computers.

Procedure. Subjects performed a memory search task, modeled after the Sternberg (1966) paradigm. On each trial, subjects were shown a memory set of one to four spatial patterns on the computer CRT screen. These spatial patterns remained on the screen until the subject pressed a designated key on a computer keyboard. At this point, a fixation cross 4.5 mm high and 4.3 mm wide appeared in the middle of the screen for 500 ms. The fixation cross was replaced by a single test pattern displayed until either the subject responded or two seconds elapsed.

The subject was instructed to rapidly determine whether the test pattern was a member of the previously presented memory set. Subjects responded "yes" or "no" by pressing a labeled response button on the keyboard. Half the test patterns in each block of trials were members of the memory set; the other patterns were not. Two dependent measures, reaction time and response accuracy, were collected. Each subject was instructed to respond as rapidly as possible while maintaining an accuracy level of at least 90 percent or higher within each session.

Visual and auditory feedback were provided to subjects at the completion of each trial. An incorrect response was followed by a "Wrong Response" message on a red background and a tone. A correct response was followed by a "Correct Response" message on a blue background, the reaction time for that trial, and a short musical sequence for those reaction times below a specified criterion. In addition, the feedback concerning correct responses included a message specifying the performance level indicated by the reaction time achieved. This feedback indicated if the performance level was that of a "Novice," "Professional," "Expert," or "Ace." These levels represented progressive decreases in reaction time to the spatial pattern information. The feedback encouraged the subject to decrease reaction time if only the "Novice" level had been achieved on a particular trial. Performance categories were based on reaction times achieved by subjects in a pilot study that preceded the present experiment.

Additional summary feedback was provided at the beginning of each day of training following the initial training day. This feedback summarized reaction time and accuracy performance levels from each previous training day and provided a means for subjects to follow changes in their performance as a function of training.

As indicated above, the experiment was divided into two phases: (a) training, and (b) transfer. Subjects participated in the training phase for four days. Each day, subjects completed four 30-minute training sessions which consisted of ten 20-trial blocks. Therefore, there were 800 acquisition trials each day and a total of 3200 acquisition trials across the training phase.

The transfer phase required one day to complete and was performed on the day following the last acquisition day. During the transfer phase, subjects completed four 30-minute training sessions, which consisted of 10 blocks of 20 trials each.

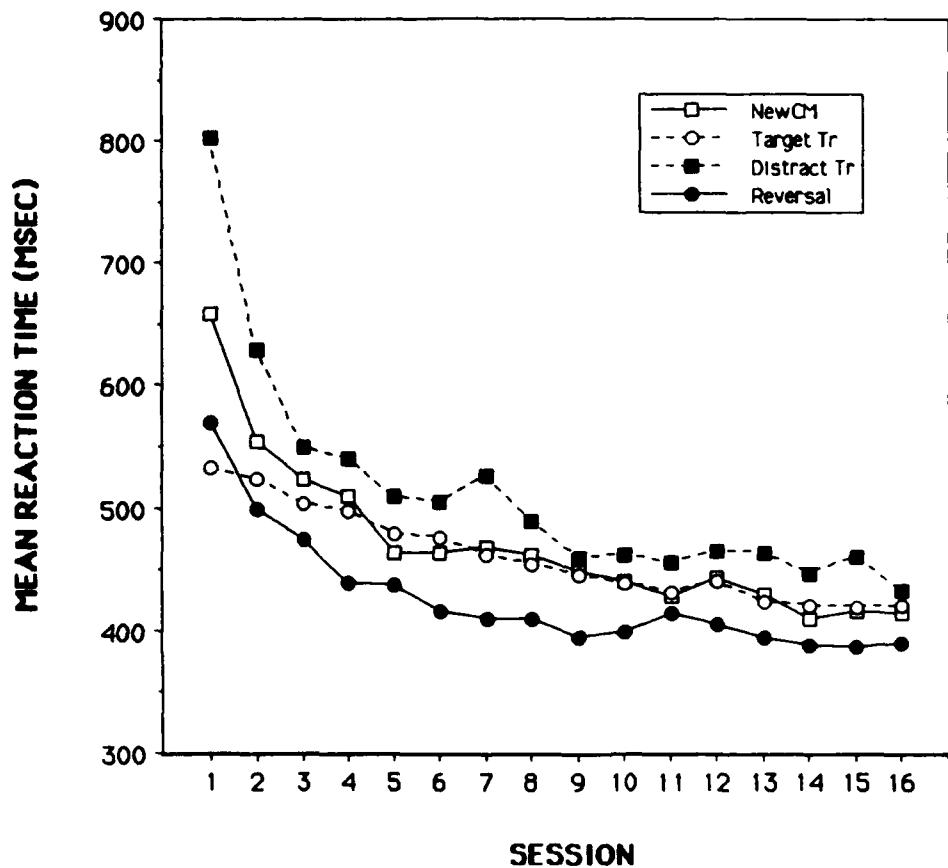
Therefore, there were 800 total trials during the transfer phase of the experiment. Subjects were randomly assigned to one of the four transfer conditions outlined above: (a) TT, (b) DT, (c) CR, and (d) NCM. As indicated previously, the NCM condition is a control that was used to evaluate transfer effects in the preceding three conditions.

Stimulus Materials. Each spatial stimulus pattern was composed of five circular elements and represented the type of pattern processed by some Air Force C<sup>2</sup> systems operators. Four different sets of patterns were developed by random selection from a total set of sixteen patterns similar to those used in the Eggemeier et al. (1990, 1991) research. Each set served as targets and distractors an equal number of times during both training and transfer for each transfer group.

Design. Three independent variables were included in the design: (a) transfer group, (b) memory set size, and (c) training/transfer sessions. Transfer group, a between-subjects variable, consisted of the four previously described transfer conditions: TT, DT, CR, and NCM. Four subjects were assigned to each transfer group. Memory set size consisting of one to four spatial patterns was manipulated within blocks of trials in each group. Each group completed 16 sessions of acquisition trials across the four days of the training phase, and four sessions of transfer during the one-day transfer phase. As noted above, all training/transfer within this experiment was conducted under CM conditions.

### Results

Training Phase Reaction Time. Mean reaction time to test patterns as a function of transfer group and training sessions is illustrated in Figure 8-1. The means depicted are based on correct responses by subjects. As shown in the figure, performance improved in all transfer groups as a function of



**Figure 8-1.** Mean Reaction Time as a Function of Transfer Group and Training Session.

training sessions; during the later sessions of transfer, there were no substantial differences between groups.

A  $4 \times 4 \times 16$  ANOVA was performed on the reaction time data to analyze the effects of transfer group (TT, DT, CR, or NCM), memory set size (1-4), and training session (1-16). Transfer group was a between-subjects variable in this analysis, while memory set size and training session were within-subjects variables. This analysis indicated that the main effects of memory set size ( $F(3,36) = 169.45$ ,  $p < .001$ ,  $MS_e = 4270.39$ ) and training sessions ( $F(15,180) = 19.32$ ,  $p < .001$ ,  $MS_e = 11806.10$ ) were significant, but that the main effect of transfer group ( $F(3,12) = 1.73$ ,  $p > .05$ ,  $MS_e = 183808.32$ ) was not. The interactions of transfer condition and training sessions ( $F(45,180) = 1.01$ ,  $p > .05$ ) and transfer condition and memory set ( $F(9,36) = 1.41$ ,  $p > .05$ ) were nonsignificant, as was the three-way interaction of transfer condition, training sessions, and memory set ( $F(135,540) = 0.99$ ,  $p > .05$ ,  $MS_e = 569.54$ ). However, the interaction of memory set and training sessions ( $F(45,540) = 7.95$ ,  $p < .001$ ) did prove to be significant.

Figure 8-2 depicts mean reaction time as a function of memory set in Sessions 1 and 16 of training. As seen in the figure, the effect of memory set size was substantially attenuated from Session 1 to Session 16. This is reflected in the reliable memory set and training sessions interaction, and is consistent with some level of automatic processing development at the conclusion of training. To characterize the effect of memory set size on mean reaction time, slopes of the functions relating memory set size to reaction time were computed for the Session 1 and Session 16 data illustrated in the figure. The slope of the Session 1 function was 68 ms, while that of the Session 16 function was 26 ms. Thus, there was a 62-percent reduction in the slope of the memory set size function across training. This reduction compares favorably with the results of previous experiments (e.g., Eggemeier et al., 1991) that used similar

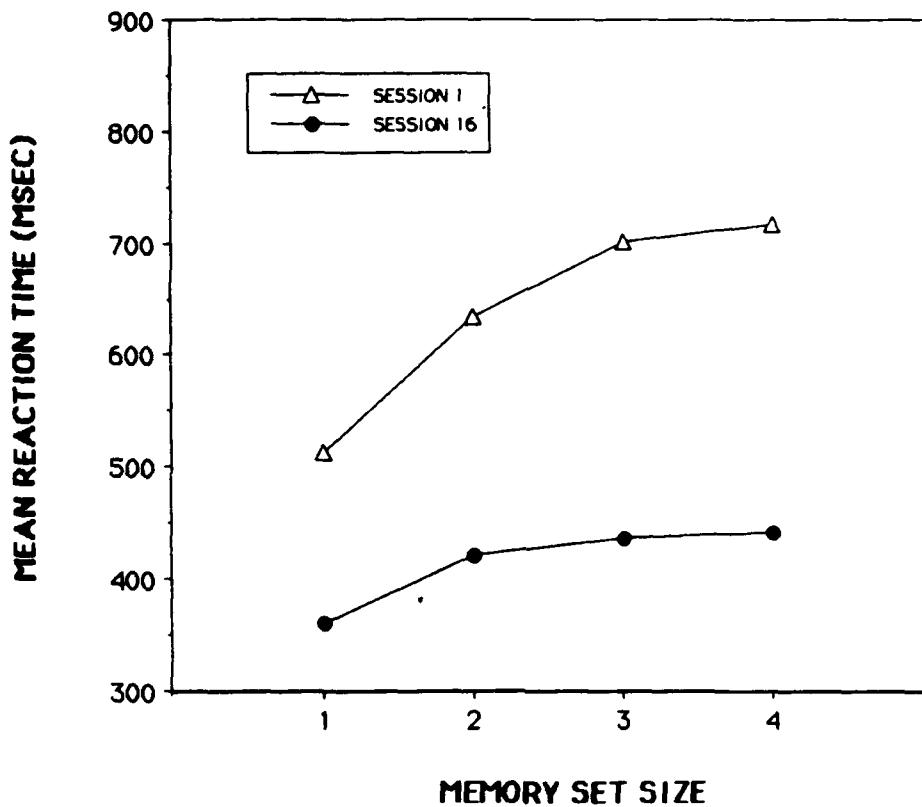


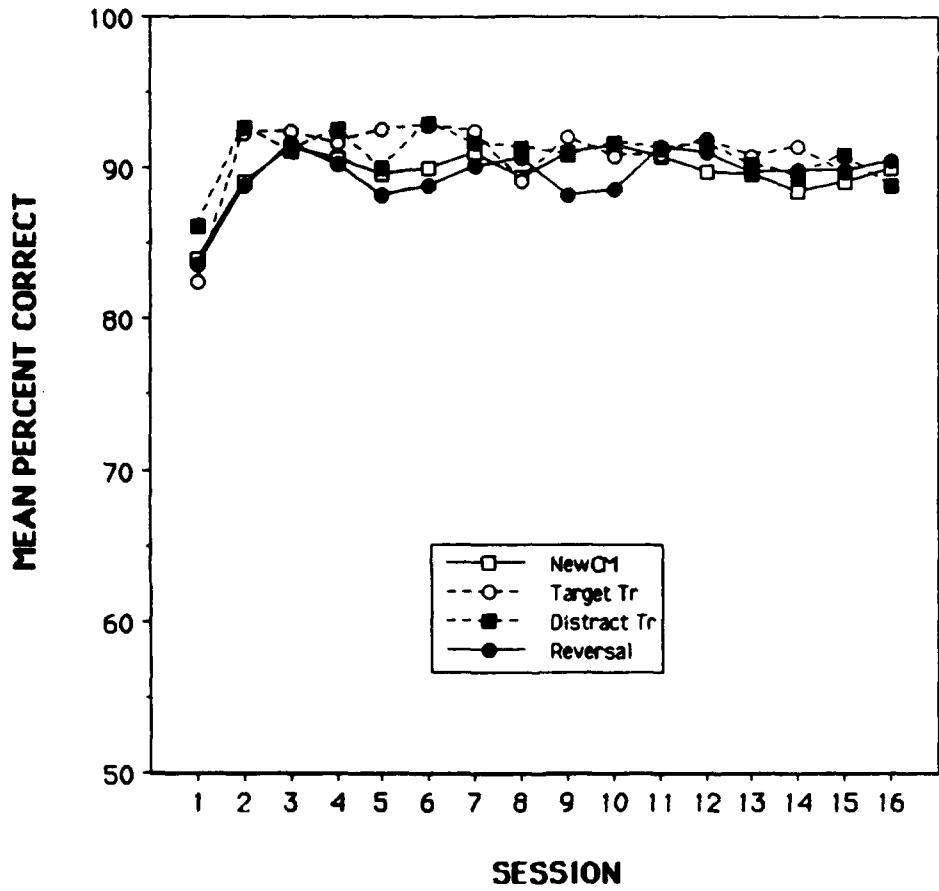
Figure 8-2. Mean Reaction Time as a Function of Memory Set Size and Training Session.

spatial pattern materials under CM conditions. It is also consistent with the development of some level of automatic processing in the present experiment.

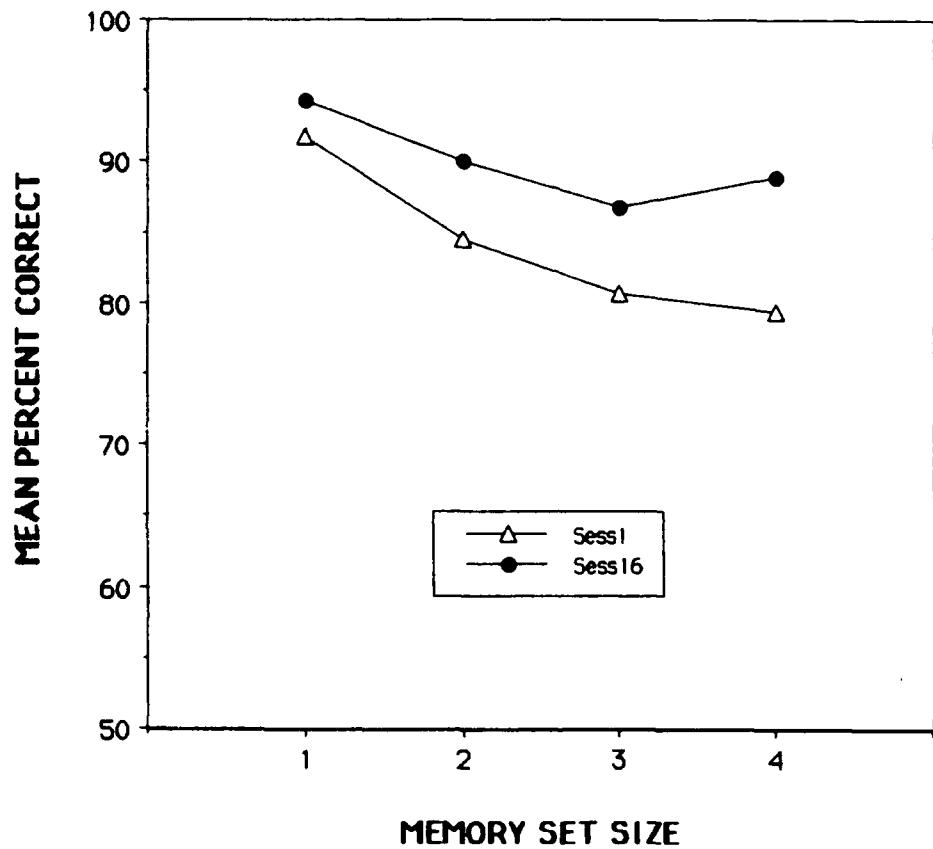
Training Phase Accuracy of Responding. Figure 8-3 shows mean percent correct responses as a function of transfer condition and training session. As illustrated in the figure, response accuracy was consistently high and improved in all transfer conditions as a function of training.

A  $4 \times 4 \times 16$  ANOVA, comparable to the reaction time analysis, was performed on the percent correct data to analyze the effects of transfer group (TT, DT, CR, or NCM), memory set size (1-4), and training sessions (1-16). The results, which paralleled those of the reaction time analysis, showed that the main effects of memory set size ( $F(3,36) = 16.34, p < .001$ ,  $MS_e = 79.23$ ) and training sessions ( $F(15,180) = 4.40, p < .001$ ,  $MS_e = 44.38$ ) were significant, but that the main effect of transfer condition ( $F(3,12) = 1.68, p > .05$ ,  $MS_e = 82.18$ ) was not. Once again, the interactions of transfer condition and training sessions ( $F(45,180) = 0.42, p > .05$ ) and transfer condition and memory set ( $F(9,36) = 1.10, p > .05$ ) were nonsignificant, as was the three-way interaction of transfer condition, training sessions, and memory set ( $F(135,540) = 0.97, p > .05$ ,  $MS_e = 18.48$ ). However, the interaction of memory set and training sessions ( $F(45,540) = 1.79, p < .005$ ) was reliable.

Figure 8-4 depicts mean percent correct performance as a function of memory set size in Sessions 1 and 16 of training. As shown in the figure, percent correct performance improved from Session 1 to 16; these improvements generally took the form of an attenuation of the memory set size effect on performance. This attenuation, reflected in the reliable memory set and training sessions interaction, parallels the improvements in performance and attenuation of memory set effects noted in reaction time. Therefore, the percent correct analysis provides no basis to



**Figure 8-3.** Mean Percent Correct as a Function of Transfer Group and Training Session.



**Figure 8-4.** Mean Percent Correct as a Function of Memory Set Size and Training Session.

infer that a speed/accuracy tradeoff was responsible for the pattern of performance improvement present in the reaction time data. The results are also consistent with some level of automatic processing development at the conclusion of training.

The overall pattern of the training phase results is consistent with the presence of some level of automatic processing in all transfer conditions at the conclusion of training. The absence of any main effects or interactions involving the training condition variable indicates that performance was equivalent across transfer groups during the training phase of the experiment. This absence facilitates direct interpretation of the transfer phase results.

Transfer Phase Reaction Time. Mean reaction time to test patterns as a function of transfer group and training/transfer sessions is illustrated in Figure 8-5. The means depicted in this figure show reaction time in the last acquisition session of the training phase and in each of the four transfer sessions. These means are based on correct responses. As shown in the figure, transfer resulted in increased reaction times in the DT, CR, and NCM conditions, but not in the TT group which continued to perform at approximately the same levels as in the last session of the training phase.

A  $4 \times 4 \times 4$  ANOVA was performed on the reaction time data to analyze the effects of transfer group (TT, DT, CR, or NCM), memory set size (1-4), and transfer sessions (1-4) on performance. Transfer group was a between-subjects variable in this analysis, while memory set and transfer sessions were within-subjects variables. This analysis demonstrated that the main effect of memory set size ( $F(3,36) = 109.50, p < .001$ ,  $MS_e = 1575.37$ ) was significant, but the main effects of transfer condition ( $F(3,12) = 1.10, p > .05$ ,  $MS_e = 32623.86$ ) and transfer sessions ( $F(3,36) = 1.88, p > .05$ ,  $MS_e = 1179.27$ ) were not. None

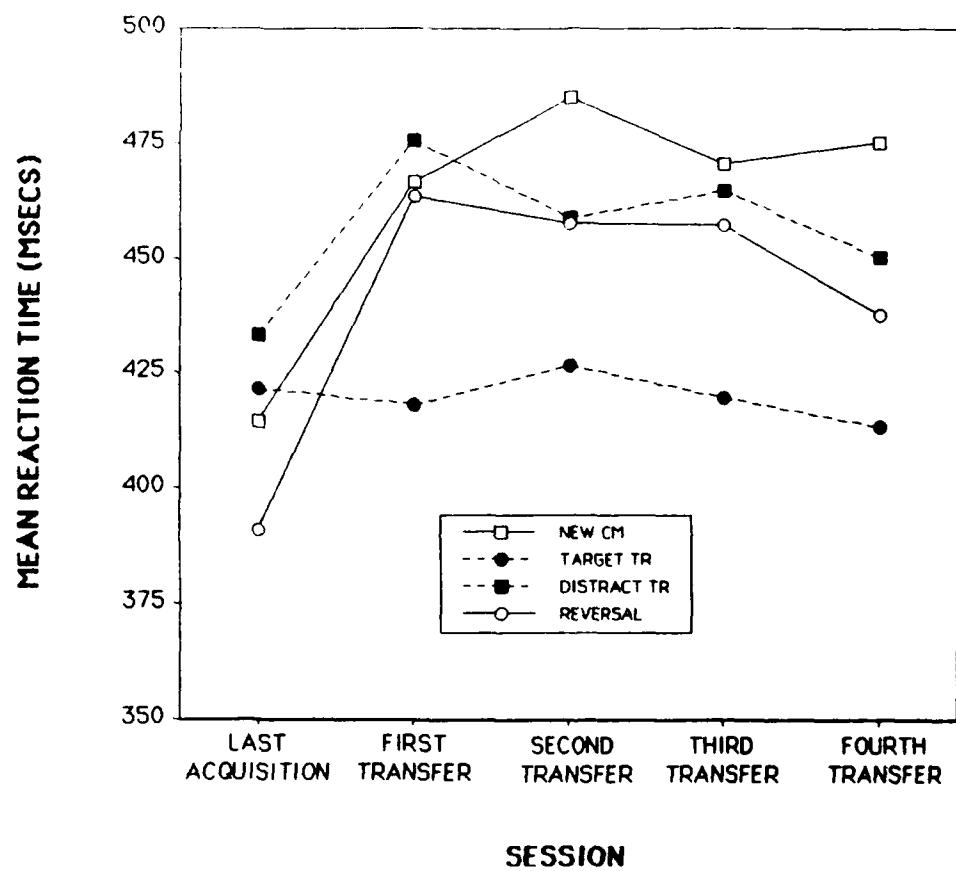


Figure 8-5. Mean Reaction Time as a Function of Transfer Group and Session.

of the interactions proved to be reliable, although the  $F$  value associated with the interaction of transfer condition and memory set size ( $F(9,36) = 2.08, p > .05$ ) approached but did not meet the value required for significance. The main effect of memory set size reflects the expected increase in reaction time at higher memory set sizes. The failure of the main effect of transfer condition or any of the interactions involving that variable to attain significance indicates that there was no reliable transfer condition effect on reaction time performance. Therefore, the previously noted trend for the TT group to demonstrate superior transfer performance is not reliable.

Transfer Phase Accuracy. Mean percent correct as a function of transfer group and training/transfer sessions is depicted in Figure 8-6. The means shown illustrate percent correct performance in the last acquisition session of the training phase and in each transfer session. As indicated by the figure, transfer resulted in an initial decrease in accuracy in the CR and NCM conditions. However, performance in the TT and DT conditions continued to approximate the levels of accuracy achieved during the last session of the training phase.

A  $4 \times 4 \times 4$  ANOVA, comparable to the reaction time analysis, was performed on the percent correct data to analyze the effects of transfer group (TT, DT, CR, or NCM), memory set size (1-4), and transfer sessions (1-4) on performance. Once again, transfer group was a between-subjects variable, while memory set size and transfer session were within-subjects variables. This analysis indicated that the main effects of transfer condition ( $F(3,12) = 4.28, p < .05, MS_e = 86.16$ ), memory set size ( $F(3,36) = 109.50, p < .001, MS_e = 1575.37$ ), and transfer sessions ( $F(3,36) = 4.07, p < .05, MS_e = 22.93$ ) were significant. The interaction of transfer condition and memory set size ( $F(9,36) = 28.07, p < .05$ ) was also significant, but none of the other interactions were reliable.

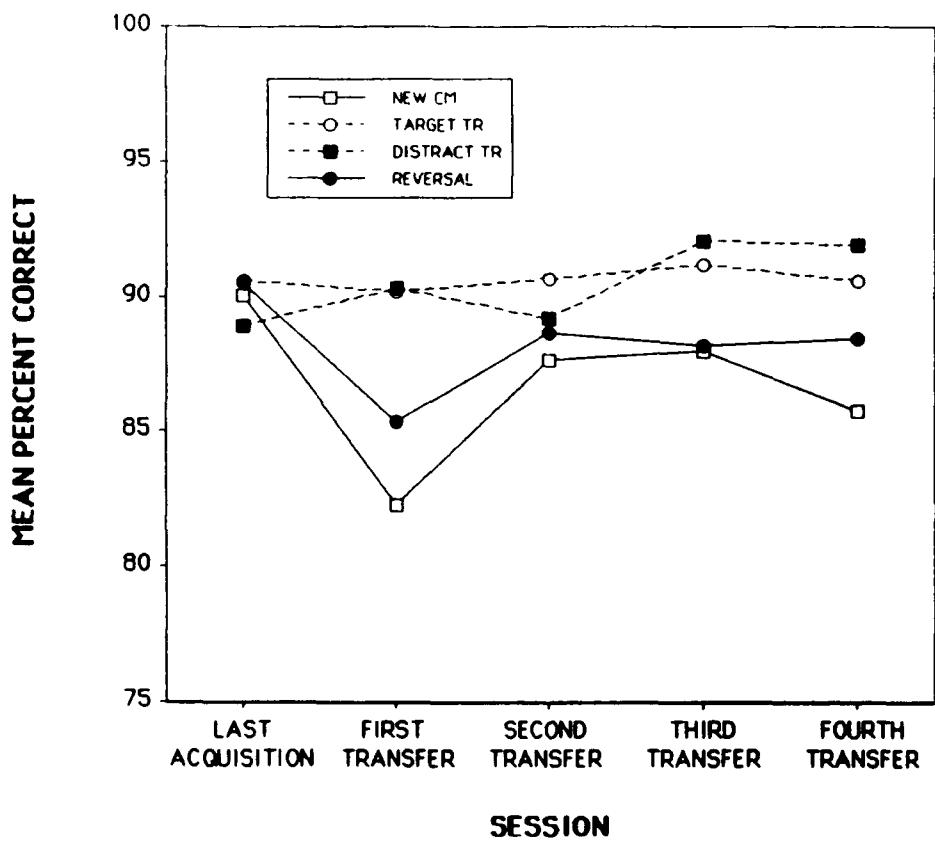
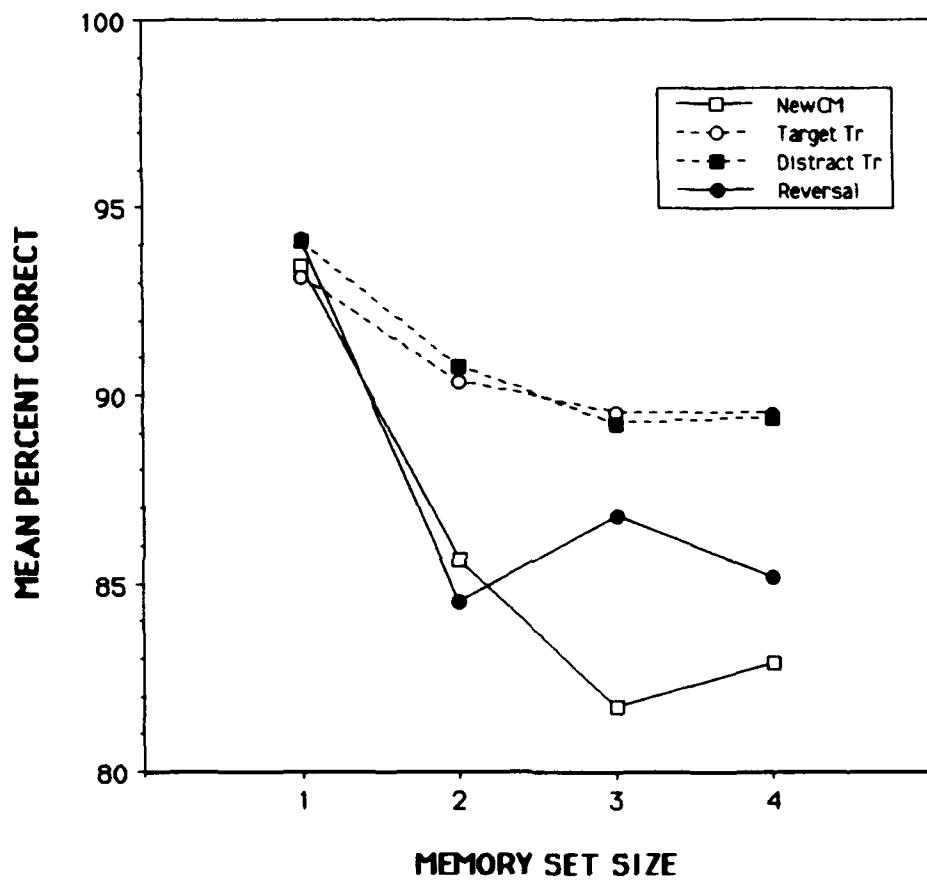


Figure 8-6. Mean Percent Correct as a Function of Transfer Group and Session.

Figure 8-7 shows mean percent correct as a function of transfer condition and memory set size. As seen in the figure, transfer condition had very little effect on performance under the memory set size one condition, but both the TT and DT conditions tended to show higher levels of accuracy than the NCM control at the higher memory set sizes. The performance of the CR group and the NCM control tended to demonstrate similar levels of performance at the higher memory set sizes. To evaluate the reliable interaction of transfer condition and memory set, tests of the transfer condition effect were conducted at each level of the memory set variable. These analyses indicated that the effect of transfer group was nonsignificant at memory set size one ( $F(3,12) = 0.15$ ,  $p > .05$ ,  $MS_e = 28.61$ ). However, the effect of transfer group was significant at memory set size two ( $F(3,12) = 4.15$ ,  $p < .05$ ,  $MS_e = 39.79$ ), memory set size three ( $F(3,12) = 3.96$ ,  $p < .05$ ,  $MS_e = 52.68$ ), and memory set size four ( $F(3,12) = 4.14$ ,  $p < .05$ ,  $MS_e = 41.06$ ).

Contrasts performed to investigate the locus of the reliable effects indicated that at memory set size two the DT condition differed reliably from the NCM control ( $F(1,12) = 5.28$ ,  $p < .05$ ). However, the TT ( $F(1,12) = 4.54$ ,  $p > .05$ ) and CR ( $F(1,12) = 0.25$ ,  $p > .05$ ) conditions were not significantly different from the NCM condition. Comparable analyses at the memory set size three condition showed that both the TT ( $F(1,12) = 9.27$ ,  $p < .05$ ) and DT ( $F(1,12) = 8.54$ ,  $p < .05$ ) conditions differed significantly from the NCM control, but that the CR condition ( $F(1,12) = 3.80$ ,  $p > .05$ ) did not. Analyses at the memory set size four condition produced parallel results and demonstrated that the TT ( $F(1,12) = 8.55$ ,  $p < .05$ ) and DT ( $F(1,12) = 8.23$ ,  $p < .05$ ) conditions differed from the NCM control, but there was no difference between the CR condition and the NCM control ( $F(1,12) = 1.04$ ,  $p > .05$ ). Therefore, both the TT and DT groups demonstrated performance superior to the NCM control at the higher memory set sizes, while the CR condition



**Figure 8-7.** Mean Percent Correct as a Function of Transfer Group and Memory Set Size.

produced performance that failed to differ reliably from the NCM control.

### Discussion

The results of the transfer phase indicate that both the TT and DT conditions produced accuracy performance superior to that of the NCM control condition. The pattern of these results suggests that both target and distractor learning occurred with spatial pattern information within the current memory search paradigm. In addition, there was a nonsignificant trend for the TT group to produce lower reaction times than those associated with the remaining conditions. On the practical level, the present results suggest that some positive transfer could be expected under operational conditions that involve either target or distractor transfer within memory search tasks.

The failure to find reliable differences between the CR and NCM control conditions was somewhat surprising, particularly since some evidence of positive transfer relative to the NCM control was obtained in the accuracy data for both the TT and DT conditions. If both target and distractor learning occurred during training, it would be expected that initial transfer performance in the CR group would have been inferior to that in the NCM control group. One possible explanation for the failure to find such differences lies in the nature of the spatial pattern information used in the present experiment. Much of the previous work (e.g., Fisk et al., 1990, 1991) with target and distractor reversal conditions used semantic category and alphanumeric information. It can be assumed that semantic category information was well-learned by subjects prior to participation in the experiment; this was not the case with the spatial pattern information in the current experiment. Consequently, one requirement for correct responding in the present experiment would have been the learning or integration of the spatial patterns themselves, without regard for their roles

as targets or distractors. This learning would have been required at initial transfer for both targets and distractors under the NCM condition and may have offset any disadvantage that would have been incurred under the reversal condition. This possibility could be investigated through future research that examines target and distractor transfer within a memory search paradigm with materials not expected to require pattern learning or integration (e.g., letters of the alphabet, numerals).

#### Summary and General Discussion

This series of experiments addressed a number of issues pertaining to the transfer of automatic processing. The results demonstrated the transfer of such processing under certain conditions, but also indicated that there appear to be important limits on transfer under other conditions.

The first two experiments in this series dealt with transfer of complex alphanumeric rules within memory search and visual/memory search paradigms, respectively. Positive transfer of previously trained rules to untrained exemplars was demonstrated under CM conditions in both experiments. In each case, transfer was evaluated with respect to a baseline condition which involved previously untrained rules and exemplars. Therefore, the results of Experiments 5 and 6 indicate that some performance benefits, established with one set of rule exemplars, do transfer to untrained exemplars of the same rules. These data suggest that operator training programs, designed to establish automatic processing of alphanumeric rules of the type used in the present work, could be structured to take advantage of this type of transfer. The results further indicate that the automatic processing established through the training completed prior to transfer was at least partially at the rule level rather than at individual exemplar level.

As described previously, the current findings are consistent with the results of previous research (e.g., Hale and Eggemeier, 1990; Hassoun and Eggemeier, 1988) which investigated transfer to untrained exemplars of trained semantic categories. This work and other recent research which has demonstrated rule-based or higher-order automatic processing (e.g., Fisk and Lloyd, 1988; Fisk et al., 1988; Kramer et al., 1990) suggest that automatic processing can be based on consistencies above the level of the individual exemplars or stimuli processed. Complex skills such as those required of C<sup>2</sup> operators are likely to incorporate such consistencies; thus the noted research supports training approaches intended to establish automatic processing in the higher-order or rule-based components of these skills.

Experiment 7 investigated the transfer associated with processing spatial patterns that had been rotated from the orientation used during original training. The data from this experiment indicated that initial performance under pattern rotation conditions eliminated performance differences between CM and VM conditions established through previous training. This result has important implications for operator training programs; C<sup>2</sup> systems can require an operator to detect and process critical pattern information in a variety of rotations. However, the results of Experiment 7 also demonstrated that some differences between CM and VM performance had been re-established with rotated patterns after a minimal number of retraining trials. Although the results of the present experiment indicate that processing of rotated patterns would suffer initially, the relatively small number of retraining trials required to re-establish some CM-VM differences suggests that the additional training required to permit efficient processing of rotated patterns might not be extensive. The number of additional training trials required to re-establish original training baseline differences between CM and VM performance was not addressed in the present experiment and represents an important issue for future research.

The final experiment in this series investigated the transfer of automatic processing under various conditions of task recombination. The results of Experiment 8 provide some evidence of both target and distractor transfer in a memory search task that required processing of spatial pattern information. This evidence was primarily obtained from analyses of performance accuracy at transfer, although there was a nonsignificant trend which suggested the presence of target transfer within the reaction time data. These results suggest that some transfer of both target and distractor pattern information could be expected under certain task recombination conditions.

An unexpected result of Experiment 8 was the failure of the CR condition to lead to negative transfer relative to the NCM control condition. This may have reflected learning or integration requirements associated with the spatial pattern information used in this experiment. Future research with other types of information will be required to address the issue of target and distractor transfer within memory search paradigms.

#### IV. RETENTION OF AUTOMATIC PROCESSING IN SEARCH TASKS REQUIRING THE PROCESSING OF COMPLEX ALPHANUMERIC AND SPATIAL PATTERN INFORMATION

The retention of automatic processing represents an important issue in the design of training programs to support the development of automatic task subcomponents within C<sup>2</sup> operator functions. Information regarding the retention functions associated with such subcomponents is essential to determine the frequency of skill maintenance or refresher training required to maintain automatic task subcomponents at acceptable performance levels over periods of disuse.

Despite the importance of automatic processing retention to training program design, there has been relatively little work (e.g., Eggemeier et al., 1991; Fisk et al., 1990, 1991; Healy,

Fendrich, and Proctor, 1990; Shiffrin and Dumais, 1981) concerning such retention functions. Fisk et al. (1990), for example, conducted a series of experiments in memory and visual/memory search tasks to examine the retention of automatic processing with semantic materials. Subsequently, Fisk et al. (1991) investigated retention functions within a complex problem-solving task intended to represent the types of demands imposed on some C<sup>2</sup> systems operators. Eggemeier et al. (1991) examined the retention of automatic processing with static spatial pattern information in a memory search task over a one-month period. They reported no reliable losses in performance over that time.

Because information regarding the retention of automatic processing is essential to training program design, it was considered important to extend previous work in this program in several ways. These included extension of earlier memory search work with spatial patterns (Eggemeier et al. 1991) to alphanumeric materials of the type processed by C<sup>2</sup> operators, and to visual/memory search functions that represent components of such operator tasks. The processing of complex alphanumeric information represents a component of many C<sup>2</sup> operator tasks. Therefore, retention functions pertaining to automatic processing of this material represent an important aspect of skill maintenance training program design. In addition, Fisk et al. (1990, 1991) have reported data that demonstrate retention differences between pure memory and visual search tasks and visual/memory search paradigms. These data showed greater retention decrements with visual/memory search than with pure search paradigms, and indicate the need for additional retention work with visual/memory search procedures.

### Overview of Present Studies

One purpose of the present series of experiments was to extend previous research (e.g., Eggemeier et al., 1991; Fisk et al., 1990, 1991) to alphanumeric information of the type processed by C<sup>2</sup> system operators within two types of search tasks (i.e., memory search, visual/memory search). A second purpose was to examine retention of static spatial pattern information within a visual/memory search paradigm.

Experiment 9 investigated the retention of letter sequences that represented system parameter designators in some C<sup>2</sup> systems. This experiment was performed within the same type of memory search paradigm used by Eggemeier et al. (1991) to investigate the retention of spatial pattern information. Experiment 10 extended the results of the Eggemeier et al. (1991) spatial pattern retention study to the type of visual/memory search paradigm investigated in Experiment 4. Experiment 10 also permitted evaluation of whole-task versus part-task training effects on the retention of spatial pattern information. Finally, Experiment 11 investigated the retention of complex alphanumeric information within the rule-based visual/memory search task investigated in Experiment 2. The retention of automatic processing in such a rule-based task had not been examined previously. Experiment 11 also afforded the opportunity to gather additional information concerning the retention of visual/memory search functions.

Experiment 9  
Retention of Automatic Processing in a Task  
Requiring the Processing of Complex Alphanumeric Information

Purpose

Some Air Force C<sup>2</sup> systems require the operator to rapidly process alphanumeric information such as multiple-letter sequences. These letter sequences can represent various system parameters, and must be rapidly and accurately identified under certain conditions in order to access information from system displays. Eggemeier et al. (1990) investigated the capability of subjects to automatize the processing of these types of letter sequences in a memory search paradigm. Subjects in the Eggemeier et al. (1990) experiment completed 3200 acquisition trials with sets of three-letter sequences under both CM and VM mapping conditions. The results demonstrated that CM performance was more rapid than VM performance, and also showed a greater attenuation of memory set size effects in the CM condition relative to the VM condition. Thus, Eggemeier et al. (1990) concluded that the results supported the development of some level of automatic processing under the CM training condition.

An important issue not addressed by the Eggemeier et al. (1990) experiment concerns the retention function associated with letter sequence information. Therefore, the purpose of the present experiment was to evaluate the effects of two retention intervals on performance with letter sequences following training under CM or VM mapping conditions. Performance was assessed after both three-day and 31-day retention intervals. Testing at each retention interval included two full retraining sessions that permitted examination of subject capability to reacquire performance levels present at the conclusion of the original training sessions.

The memory search task in this experiment used target and distractor sets which consisted of three-letter sequences (e.g., SNK, GLX) that were dissimilar and therefore highly distinguishable from one another. These sets were the same as those used by Eggemeier et al. (1990) in the previous work that examined automatic processing of letter sequence information.

### Method

Subjects. Subjects were 24 University of Dayton students who were paid \$4.00/hour. Subjects were awarded a bonus payment of \$1.00/hour for appearing on time for each scheduled session.

Apparatus. The experiment was controlled with a Zenith Data Systems 248 computer. The computer presented stimuli, controlled the timing of stimulus presentation, collected subject responses, and presented visual and auditory feedback after each trial. Subjects viewed letter-sequence stimuli on a Zenith ZCM-1490 high-resolution, thirteen-inch color monitor. Responses were made on the arrow keys located in the lower right-hand corner of a standard expanded IBM-compatible keyboard. Auditory feedback concerning performance levels was provided to subjects through the Zenith 248 speaker system.

Procedure. Subjects performed a memory search task similar to the Sternberg (1966) paradigm. On each trial, a memory set of one to four letter sequences was presented on the computer CRT screen. These letter sequences remained on the screen until the subject pressed a designated key on a computer keyboard. When the key was pressed, a fixation cross (4.5 mm high and 4.33 mm wide) appeared in the middle of the screen for 500 ms. The fixation cross was replaced by a single test sequence, which was displayed until either the subject responded or two seconds elapsed.

Subjects were instructed to determine if the test sequence had been a member of the previously presented memory set. Subjects responded "yes" or "no" by pressing a labeled response button on the keyboard. Half the target stimuli in each block of trials were drawn from the memory set; the other stimuli were not. Measures of both reaction time and response accuracy were recorded. Each subject was instructed to respond as rapidly as possible while maintaining a 90-percent accuracy level or higher within each session.

Visual and auditory feedback was provided to subjects at the completion of each trial. After each trial, an incorrect response was followed by a "Wrong Response" message on a red background and a tone. A correct response was followed by a "Correct Response" message on a blue background, the reaction time for that trial, and a short musical sequence for those reaction times below the specified criterion of 400 ms.

Summary feedback was provided at the completion of each session. This feedback summarized reaction time and accuracy performance levels from each previous training session, and permitted subjects to track changes in their performance as a function of training.

The experiment was divided into two phases: (a) training, and (b) retention. Subjects participated in the training phase for four days. Four training sessions, each consisting of ten 20-trial blocks, were completed each day. This resulted in 800 training trials per day and a total of 3200 training trials for the first phase of the experiment.

During the retention phase, subjects returned for two retraining periods that consisted of two sessions each. Each session included 10 blocks of 20 retraining trials, for a total of 400 retraining trials across the two retraining sessions. The first retraining period took place three days after completion of

the last training session; the second retraining period was conducted 31 days after completion of the last training session.

Each retraining period included 200 warm-up trials prior to the start of the actual retraining sessions. These warm-up trials, which involved performance of a memory search task with digits, were intended to re-familiarize subjects with the general procedures of the experiment. The information used was not expected to provide any specific transfer to the letter sequence material under investigation.

The letter sequences used during retraining sessions were the same for each subject as those used during the original training sessions. Mapping conditions also remained consistent throughout the training and retention testing for each subject.

Stimulus Materials. Each three-letter sequence was intended to represent a type of alphanumeric information processed by some Air Force systems operators. These operators must rapidly and accurately process alphanumeric sequences associated with particular system parameters.

Four sets of letter sequences composed of four stimuli each were chosen from the 50-percent association value letter sequences in the Underwood and Schultz (1960) norms. Sequences in each set were chosen to be highly distinguishable from one another, such that no sequence included a letter that appeared in the same serial position in another sequence. That is, the first, second, and third letter of each sequence differed from the letters in the corresponding serial position in the other sequences. These sets were chosen to minimize any similarity or potential confusion between target and distractor items. For CM conditions, two sets were designated as targets and two sets as distractors. Exactly the same letter sequences were used in VM conditions, except that the target/distractor set distinction was not relevant.

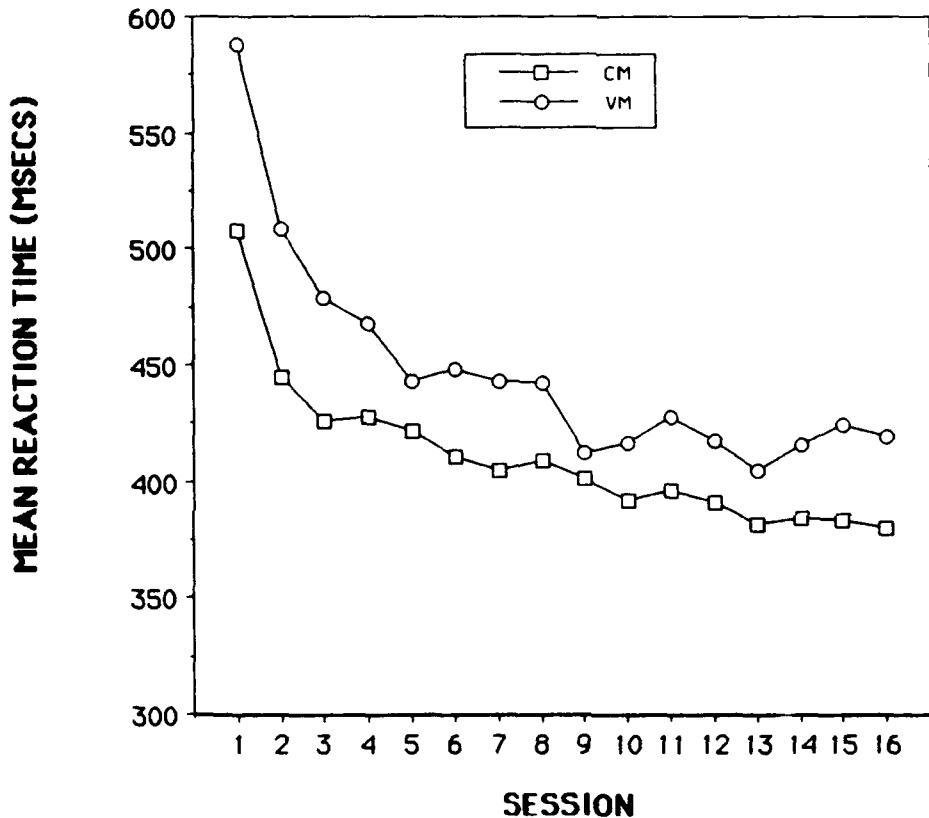
### Design

Three independent variables were included in the design: (a) target/distractor mapping, (b) memory set size, and (c) training/retraining sessions. Target/distractor mapping was either CM or VM and represented a between-subjects variable. Twelve subjects were assigned to the CM group and 12 to the VM group. In the CM condition, one set of sequences served as targets throughout training for an individual subject; a second set served as distractor patterns. In the VM condition, sets of target sequences served as both targets and distractors across blocks of trials. Memory set size, consisting of one to four sequences, was manipulated within blocks of trials in each group. Each group completed 16 sessions of practice trials across the four days of training.

### Results

Training Phase. Mean reaction time to test stimuli as a function of CM/VM condition and training sessions is illustrated in Figure 9-1. The means are based on correct responses. As seen in the figure, both mapping condition and sessions had an effect on reaction time. Reaction times were consistently lower in the CM versus the VM group, but improved as a function of training in both groups.

A 2 x 4 x 16 ANOVA was performed on the reaction time data to analyze the effects of mapping condition (CM versus VM), memory set size (1-4), and training sessions (1-16). Mapping condition was a between-subjects variable in this analysis, while memory set size and training session were within-subjects variables. The results showed significant effects of mapping condition ( $F(1,22) = 6.80$ ,  $p < .02$ ,  $MS_e = 78631.1$ ), memory set size ( $F(3,66) = 333.16$ ,  $p < .001$ ,  $MS_e = 2485.97$ ), and training sessions ( $F(15,330) = 52.03$ ,  $p < .001$ ,  $MS_e = 2824.35$ ). The

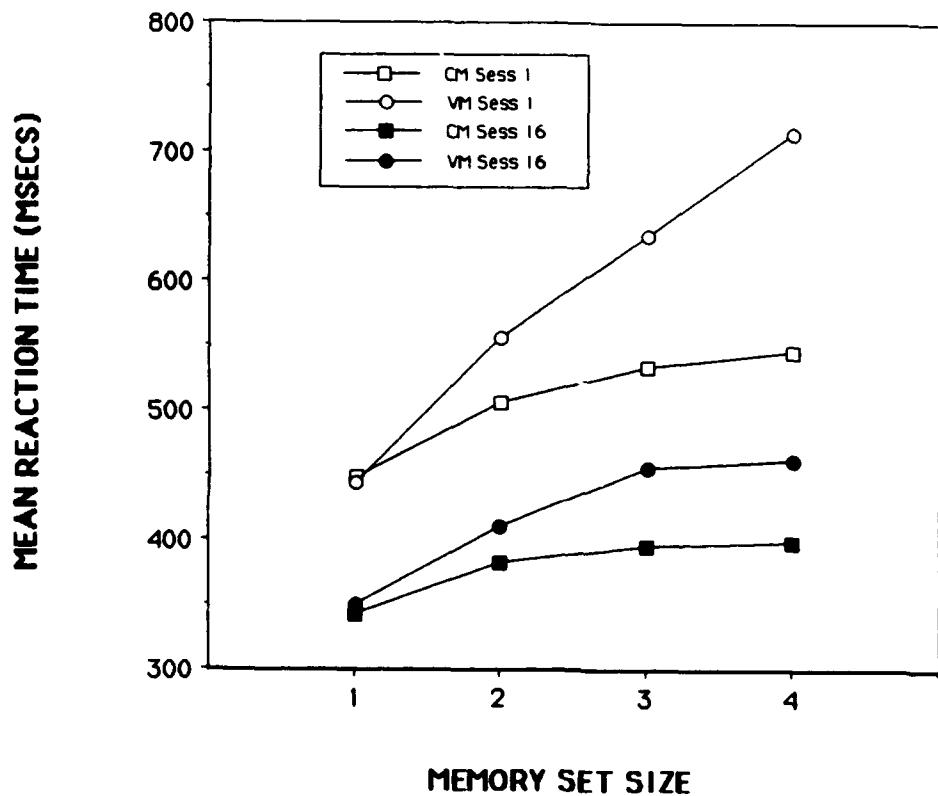


**Figure 9-1.** Mean Reaction Time as a Function of Mapping Condition and Session.

interactions of CM/VM and memory set ( $F(3,66) = 38.51, p <.001$ ), CM/VM and sessions ( $F(15,330) = 2.39, p <.05$ ), memory set and sessions ( $F(45,990) = 9.92, p <.001, MS_e = 371.56$ ), and the three-way interaction of CM/VM, memory set, and sessions ( $F(45,990) = 3.48, p <.001$ ) were also significant.

To further investigate the significant three-way interaction, an ANOVA which included mapping condition and memory set was performed on the data of Sessions 1 and 16. These sessions were chosen because interest in the present study focused on performance levels achieved in CM and VM conditions at the beginning and end of training. Figure 9-2 shows the effect of memory set on reaction time in both the CM and VM conditions during Sessions 1 and 16. It also illustrates the basis of the three-way interaction. As shown in the figure, the effect of memory set on reaction time was quite pronounced during Session 1 in both mapping conditions, but was considerably reduced during Session 16, particularly in the CM condition.

The Session 1 analysis showed that the main effect of mapping condition was not significant ( $F(1,22) = 3.90, p >.05, MS_e = 38890.95$ ), but the main effect of memory set ( $F(3,66) = 78.92, p <.001, MS_e = 1889.87$ ) and the interaction of CM/VM and memory set ( $F(3,66) = 17.25, p <.001$ ) were reliable. To further investigate the reliable interaction, tests of the simple effects of memory set were conducted within the CM and VM conditions. These analyses revealed significant memory set effects within both the CM ( $F(3,66) = 11.83, p <.001$ ) and VM ( $F(3,66) = 84.34, p <.001$ ) conditions. Tukey HSD post-hoc analyses indicated that within the CM condition, memory set size one differed reliably from all other memory set size conditions at the .05 level. No other differences were significant. Within the VM condition, all memory set sizes differed significantly from one another. The slope of the CM Session 1 function, depicted in Figure 9-2, was 31.9 ms, as compared with a 88.9 ms slope in the VM condition. Therefore, at the conclusion of the

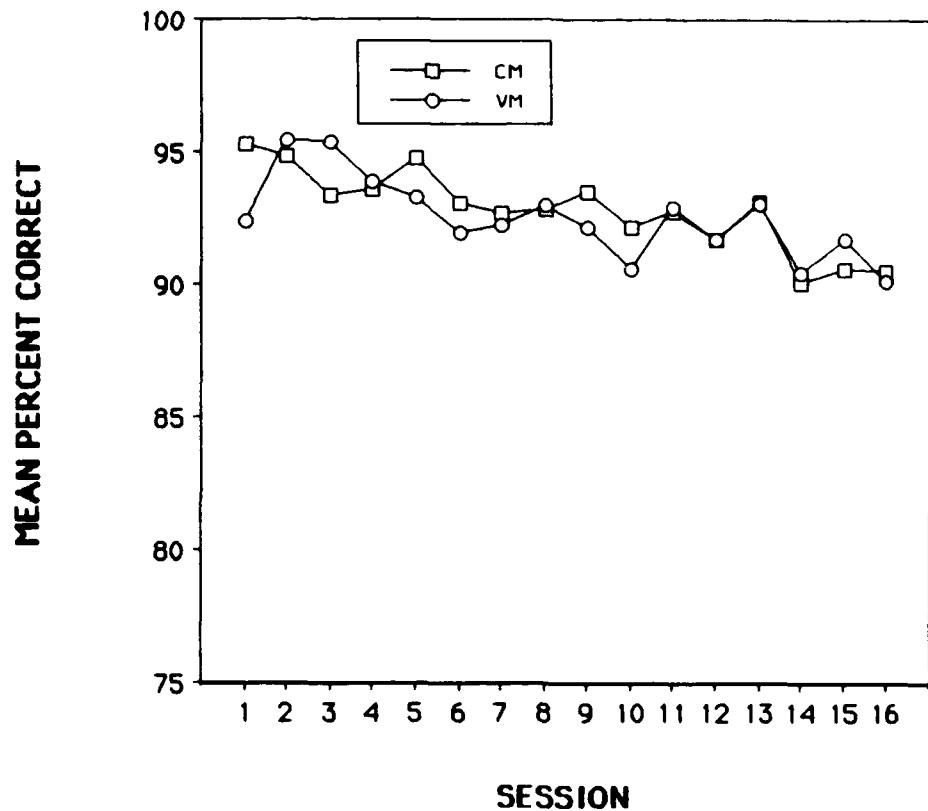


**Figure 9-2.** Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Session.

Session 1 training, the CM condition showed some attenuation of the memory set size effect relative to the VM condition. However, as expected, there was no main effect of mapping condition during the initial session of training.

The Session 16 analysis did demonstrate a significant effect of mapping condition ( $F(1,22) = 7.73$ ,  $p < .05$ ,  $MS_e = 4821.25$ ), and also showed that the main effect of memory set ( $F(3,66) = 55.86$ ,  $p < .001$ ,  $MS_e = 636.20$ ) and the CM/VM and memory set interaction ( $F(3,66) = 6.43$ ,  $p < .01$ ) were reliable. To further investigate the significant interaction, tests of the main effect of memory set were conducted within the CM and VM conditions. These analyses showed significant memory set effects within both the CM ( $F(3,66) = 12.79$ ,  $p < .001$ ) and the VM ( $F(3,66) = 49.50$ ,  $p < .001$ ) conditions. Tukey HSD post-hoc analyses were performed; the results indicated that within the CM condition, memory set sizes three and four differed from memory set size one. No other differences were significant. Within the VM condition, memory set size one differed significantly from all other memory set sizes, and memory set size four differed reliably from memory set size two. Thus, there was less attenuation of the memory set size effect under the VM condition than the CM condition. Slopes of the Session 16 functions, illustrated in Figure 9-2, confirmed this trend. The slopes were 18.3 ms and 37.7 ms in the CM and VM conditions, respectively. Therefore, at the conclusion of training, the slope of the VM function was more than two times that of the CM function. The reduction in the effect of higher memory set sizes on CM reaction time is consistent with some level of automatic processing development in this group. The difference in reduction between the CM and VM conditions is the basis for the noted interaction.

Figure 9-3 shows mean percent correct responses as a function of CM/VM group and training sessions. As shown in the figure, response accuracy consistently met or exceeded the



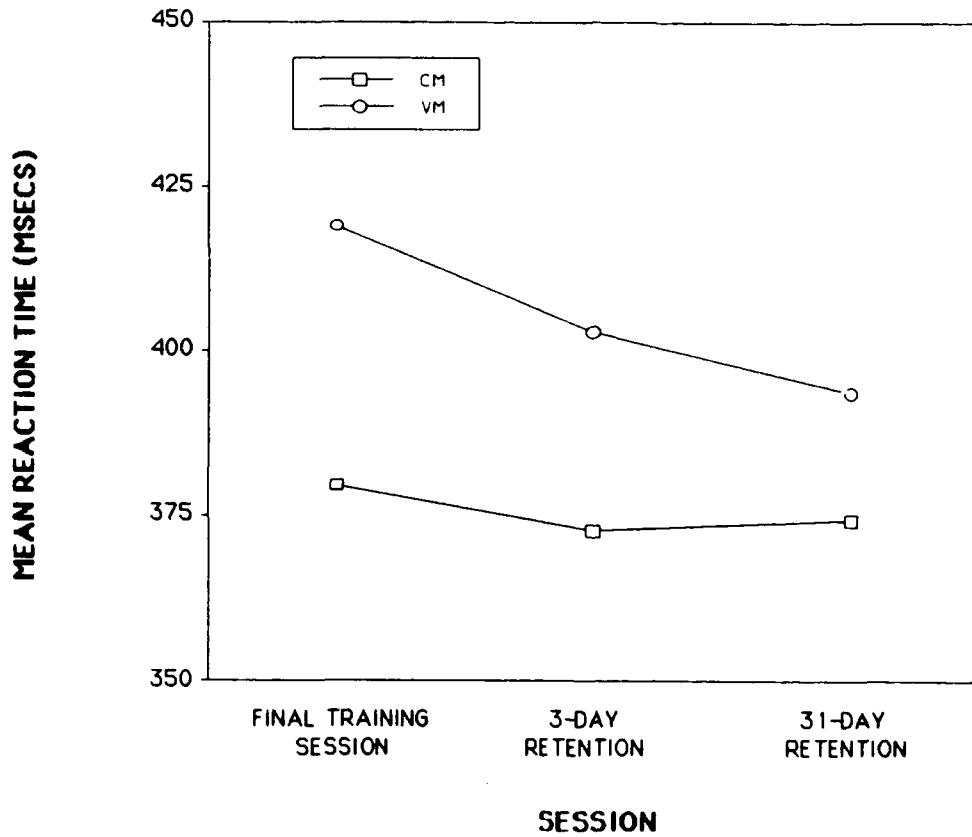
**Figure 9-3.** Mean Percent Correct as a Function of Mapping Condition and Session.

90-percent criterion set for subjects. There were no mapping condition differences of substantial magnitude.

A  $2 \times 4 \times 16$  ANOVA, comparable to the reaction time analysis, was performed on the percent correct data. The results showed no significant main effect of mapping condition ( $F(1,22) = 0.15$ ,  $p > .05$ ,  $MS_e = 217.5$ ). The analysis did demonstrate reliable effects of sessions ( $F(15,330) = 7.25$ ,  $p < .001$ ,  $MS_e = 26.56$ ) and memory set size ( $F(3,66) = 35.13$ ,  $p < .001$ ,  $MS_e = 66.02$ ). The interaction of memory set and sessions was also significant ( $F(45,990) = 1.48$   $p < .05$ ,  $MS_e = 15.02$ ). None of the other interactions were reliable. The main effect of sessions reflects a tendency in both groups for subjects to more closely approximate the 90-percent criterion as training progressed. Neither the main effect of mapping condition nor any of the interactions involving mapping condition reached significance; therefore, the previously noted differences in CM and VM reaction time performance cannot be attributed to a speed/accuracy tradeoff.

The results of the training phase of this experiment are therefore consistent with some level of automatic processing development at the conclusion of practice.

Retention Analysis. Figure 9-4 shows mean reaction time as a function of mapping condition in the last session of the training phase, the first retraining session of the three-day retention interval, and the first retraining session of the 31-day retention interval. Mean reaction times in the figure are based on correct responses. As shown in the figure, CM performance was consistent across both the three-day and 31-day retention intervals, and was superior to VM performance at each interval. VM performance, which tends to be more highly variable than CM performance, appeared to show some improvement across the two retention intervals.



**Figure 9-4.** Mean Reaction Time as a Function of Mapping Condition and Session.

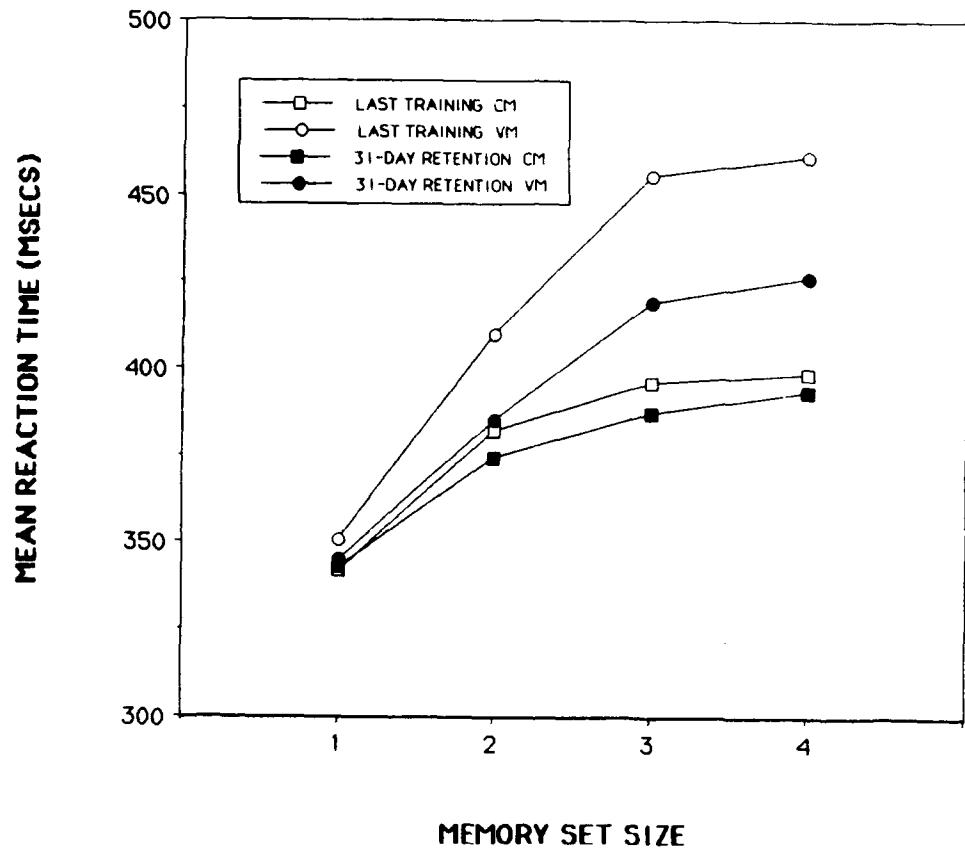
A 2 x 4 x 3 ANOVA was performed on the retention reaction time data to evaluate the effects of mapping condition (CM versus VM), memory set size (1-4), and training/retention sessions (last training session, first three-day retention session, and first 31-day retention session) on performance. This analysis demonstrated main effects of mapping condition ( $F(1,22) = 5.17$ ,  $p < .05$ ,  $MS_e = 12170.79$ ), memory set size ( $F(3,66) = 97.48$ ,  $p < .001$ ,  $MS_e = 834.27$ ), and sessions ( $F(2,44) = 3.58$ ,  $p > .05$ ,  $MS_e = 673.05$ ). The interactions of CM/VM and sessions ( $F(2,44) = 3.58$ ,  $p < .05$ ), CM/VM and memory set ( $F(3,66) = 8.21$ ,  $p < .001$ ), and sessions and memory set ( $F(6,132) = 3.49$ ,  $p < .01$ ,  $MS_e = 177.71$ ) all proved to be significant. The three-way interaction was nonsignificant.

Sessions analyses were performed within the CM and VM conditions to further explore the CM/VM and sessions interaction. These analyses revealed that there was no reliable effect of sessions on CM performance ( $F(2,44) = 0.90$ ,  $p > .05$ ,  $MS_e = 168.26$ ), but there was a significant effect of session on VM performance ( $F(2,44) = 11.72$ ,  $p < .01$ ). A Tukey HSD analysis indicated that VM reaction times associated with the last training session were reliably higher than the reaction times associated with both the three-day and 31-day retention sessions. The latter two sessions did not differ from each other. Thus, there was a significant trend for VM performance to improve over both retention intervals relative to the last training session baseline. However, there was no such improvement at the 31-day retention interval relative to the three-day retention interval baseline. This indicated that VM performance failed to change reliably over the 28 days between the two retention tests.

The failure to find evidence of improvement in the VM condition at the 31-day retention test relative to the three-day retention baseline suggests that the last training session may not constitute an ideal baseline for evaluation of retention effects in the VM condition. Figure 9-1, for example, shows that

within the four sessions performed on each of the last three original training days, VM performance was typically highest in those sessions (i.e., Sessions 5, 9, 13) that constituted the first training period each day. As sessions progressed during each training day, there was a tendency for reaction times to show some increase, such that the reaction time associated with the last training session (Session 16) of the last training day is actually higher than that associated with the first training session that day (Session 13). The potential reasons for the noted trend are not clear; however, some fatigue effect within the VM condition represents one factor which may have contributed to the trend. Another possibility is that some level of proactive interference may accumulate as a function of training trials within the VM condition. Consequently, the last training session may actually represent a somewhat conservative estimate of maximum VM performance levels in a training day. Thus, the use of this somewhat conservative estimate of final maximum VM performance may have contributed to the apparent increase in VM performance over the two retention intervals. It is important to reiterate that no such improvement was detected between 3 and 31 days of retention, indicating that VM performance was actually stable over that 28-day retention period.

Figure 9-5 illustrates mean reaction time as a function of memory set size and mapping condition during the last session of training and during the 31-day retention session. As shown in the figure, the CM group continued to exhibit a more marked attenuation of the memory set size effect than the VM group. This continued attenuation is the basis of the mapping condition and memory set size interaction that proved reliable in the overall retention analysis. The slopes of the functions relating memory set size to reaction time reflected these attenuation differences. These slopes were 18.3 ms and 37.7 ms in the CM and VM conditions, respectively, in the last training session. Comparable slopes were 16.3 ms and 27.6 ms for the respective conditions in the 31-day retention session.

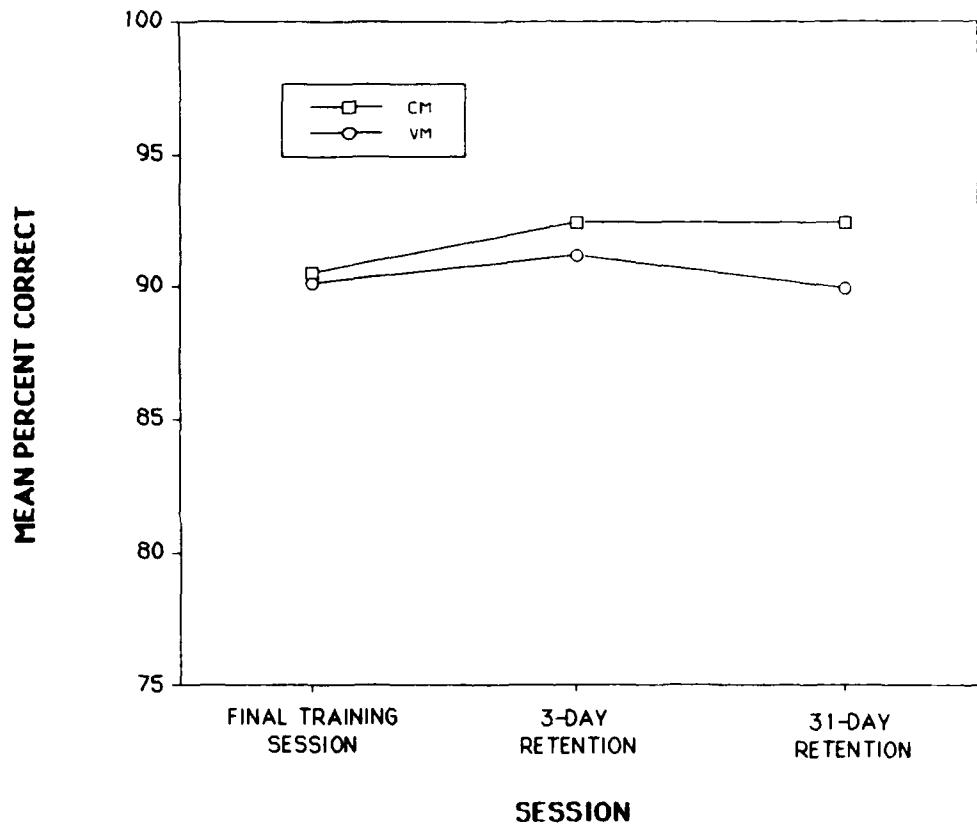


**Figure 9-5.** Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Session.

Mean percent correct responses as a function of mapping condition in the last session of training, the first session of the three-day retention test, and the first session of the 31-day retention test are shown in Figure 9-6. As seen in the figure, there was a trend for performance to show some slight improvement over both the three-day and 31-day retention intervals relative to the last training session. This trend appears most marked and consistent in the CM condition, while the VM condition shows a tendency to improve at the three-day retention test but decline at the 31-day retention test.

A 2 x 4 x 3 ANOVA, comparable to the analysis performed on the reaction data, was conducted on the percent correct data illustrated in Figure 9-6. This analysis evaluated the effects of mapping condition (CM versus VM), memory set size (1-4), and training/retention sessions (last training versus first three-day retention versus first 31-day retention) on percent correct performance. Results of this analysis showed that the main effect of mapping condition ( $F(1,22) = 1.44$ ,  $p > .05$ ,  $MS_e = 92.45$ ) was not significant, but the main effects of memory set size ( $F(3,66) = 31.63$   $p < .001$ ,  $MS_e = 27.01$ ) and sessions ( $F(2,44) = 4.10$ ,  $p < .05$ ,  $MS_e = 13.5$ ) were reliable. The CM/VM and memory set size interaction ( $F(3,66) = 5.01$ ,  $p < .005$ ) was also reliable. None of the other interactions proved to be significant.

A Tukey HSD test was performed to evaluate the main effect of sessions. It indicated that performance during the three-day retention test was reliably more accurate than during the last training session and the 31-day retention test. This trend may reflect a combination of the previously noted tendency for some depression of performance levels during the final session of training, and some slight loss of information between the three-day retention test and the 31-day test. The former factor would account for the slight performance improvement at the



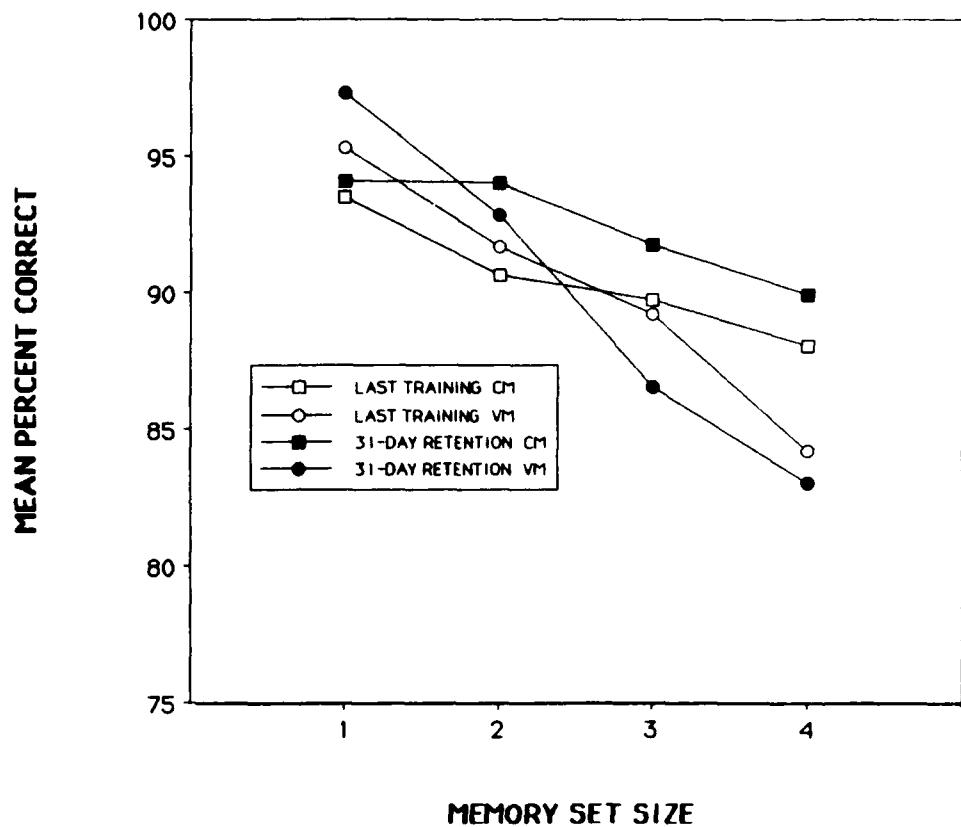
**Figure 9-6.** Mean Percent Correct as a Function of Mapping Condition and Session.

three-day interval relative to the last training session; the latter would account for the slight performance decrement at 31 days relative to the three-day retention baseline. Although the CM/VM and sessions interaction was not reliable, the tendency for loss of information that occurred at the 31-day retention interval appears to have been most pronounced within the VM condition.

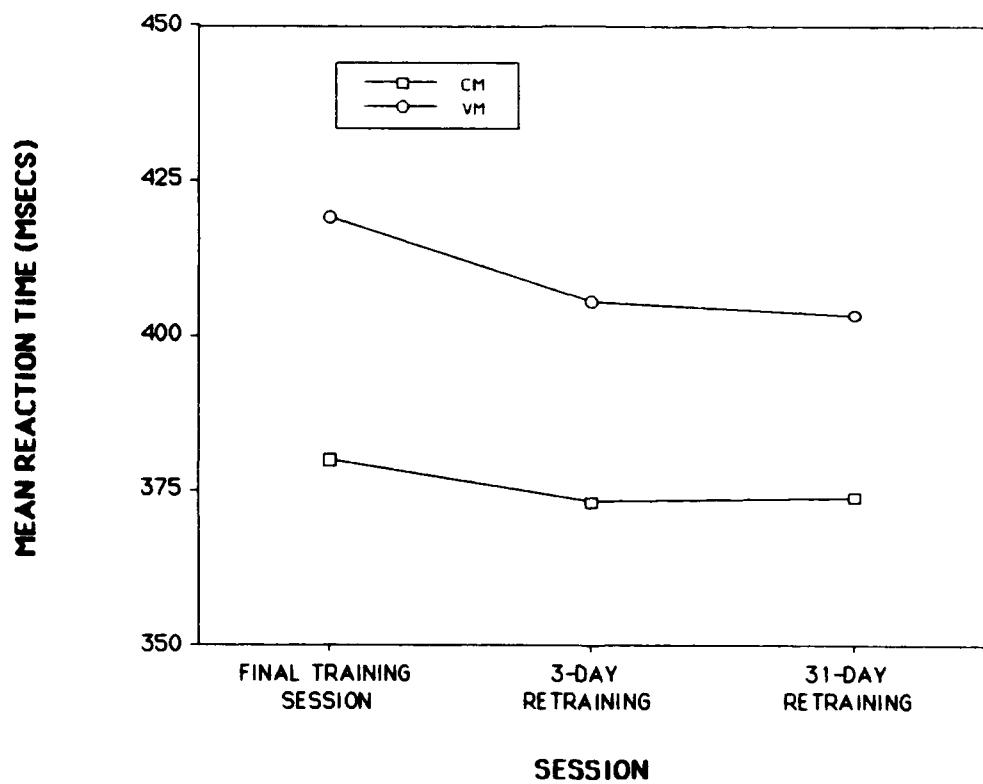
Figure 9-7 depicts mean percent correct as a function of memory set size and mapping condition during the last session of training and the 31-day retention session. As illustrated in the figure, the effect of memory set on accuracy of performance was less pronounced under the CM than VM condition. This difference served as the basis for the CM/VM and memory set interaction that proved reliable in the retention analysis.

Retraining Analysis. Comparison of the final retraining session under both the three-day and 31-day retention intervals permits evaluation of the effect of relatively short retraining periods on performance under CM and VM conditions. Figure 9-8 shows mean reaction time as a function of mapping condition for the last training session, the last session of the three-day retention interval retraining test, and the last session of the 31-day retention interval retraining test. Mean reaction times are based on correct responses. The pattern of the data illustrated in Figure 9-8 is very similar to that shown in Figure 9-4. As seen in Figure 9-8, there is a mapping condition effect on performance at the completion of the final training session and both retraining sessions, with the CM group demonstrating superior performance. Relative to the final training session, both the CM and VM groups show some tendency to improve across the retraining sessions.

A  $2 \times 4 \times 3$  ANOVA was performed on the data illustrated in Figure 9-8 to evaluate the effects of mapping condition (CM versus VM), memory set size (1-4), and training/retraining



**Figure 9-7.** Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Session.

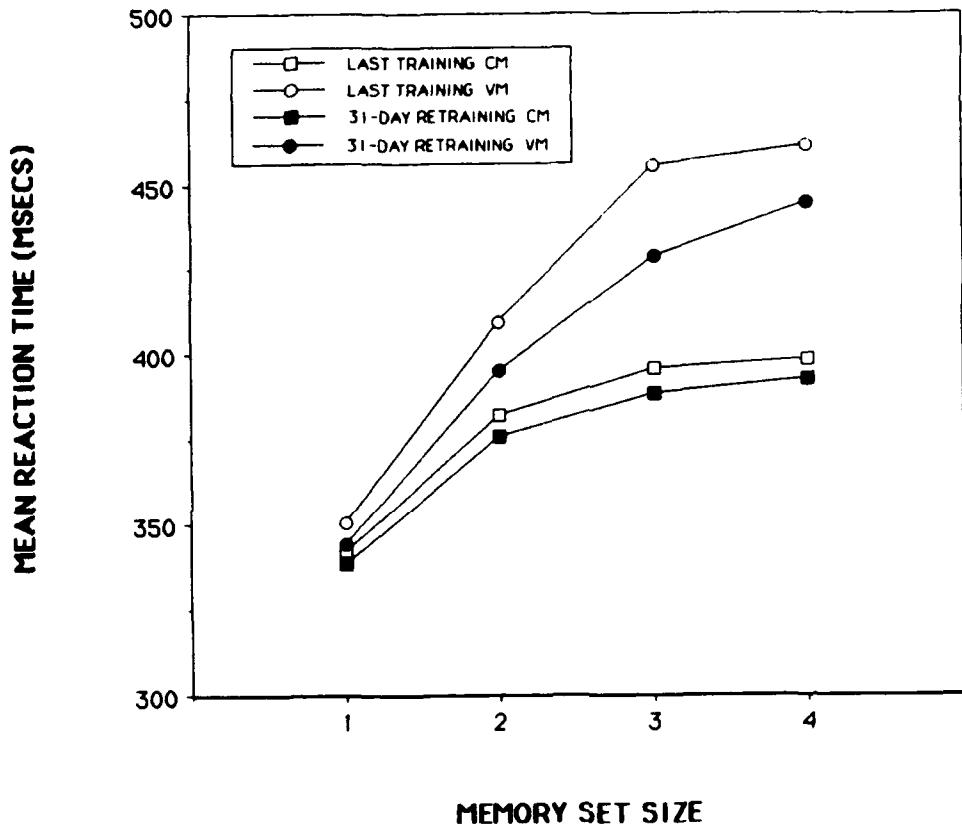


**Figure 9-8.** Mean Reaction Time as a Function of Mapping Condition and Session.

sessions (last training session versus last three-day retraining session versus last 31-day retraining session) on performance. This analysis demonstrated significant main effects of mapping condition ( $F(1,22) = 7.89$ ,  $p < .05$ ,  $MS_e = 10321.20$ ), memory set size ( $F(3,66) = 110.85$ ,  $p < .001$ ,  $MS_e = 851.32$ ), and sessions ( $F(2,44) = 3.73$ ,  $p < .05$ ,  $MS_e = 961.02$ ). The interaction of CM/VM and memory set ( $F(3,66) = 10.41$ ,  $p < .001$ ) was reliable, but none of the other interactions were significant. The main effect of mapping condition indicates that CM performance was reliably faster than VM performance across sessions, and the main effect of memory set reflects the expected trend for higher memory set sizes to be associated with longer reaction times.

A Tukey HSD analysis was performed to investigate the main effect of sessions. The results indicated that the difference between the last training session and the last 31-day retraining session, and the difference between the last training session and the last three-day retraining session approached but did not meet the value required for significance at the .05 level. The Tukey HSD is a somewhat conservative post-hoc multiple comparisons test; therefore, a Fisher Least Significant Difference (LSD) test (Kirk, 1982) was also performed on the sessions effect. The LSD test, less conservative than the Tukey HSD test, showed that the differences between the last training session and both the three-day and the 31-day retraining sessions were reliable at the .05 level. Thus, there was some tendency for reaction time performance to improve at the conclusion of each retraining session relative to the last session of training.

Figure 9-9 shows mean reaction time as a function of mapping condition and memory set size in both the last session of original training and the last retraining session of the 31-day retention interval. As demonstrated in the figure, the CM group showed a greater attenuation of the memory set effect than the VM group in both sessions. This difference in the memory set size effect forms the basis of the mapping condition and memory set

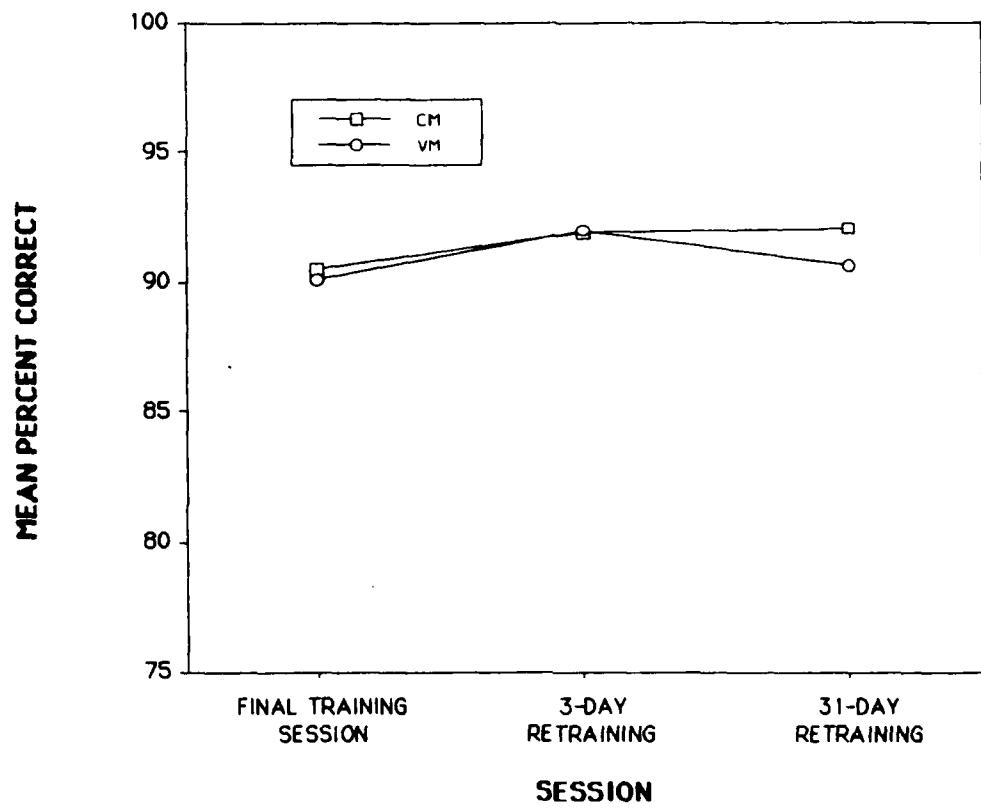


**Figure 9-9.** Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Session.

interaction that proved reliable in the retraining analysis. Once again, the slopes of the functions relating reaction time to memory set size reflected these differences. Within the last training session, the slopes of the CM and VM functions were 18.3 ms and 37.7 ms, respectively. Comparable slopes during the last retraining session were 17.4 ms in the CM group and 33.4 ms in the VM group.

Figure 9-10 illustrates mean percent correct responses as a function of mapping condition in the last session of training, the last retraining session of the three-day retention test, and the last retraining session of the 31-day retention test. As seen in the figure, accuracy levels were high at the conclusion of retraining in both CM and VM conditions, but showed some tendency to increase, particularly at the conclusion of the three-day retraining session.

A  $2 \times 4 \times 3$  ANOVA, comparable to the previous reaction time analysis, was performed on the percent correct retraining data. This analysis evaluated the effects of mapping condition (CM versus VM), memory set size (1-4), and training/retention sessions (last training session versus last three-day retraining session versus last 31-day retraining session) on percent correct performance. The results of this analysis showed no main effect of mapping condition ( $F(1,22) = 0.41$ ,  $p > .05$ ,  $MS_e = 60.41$ ), but did show main effects of memory set size ( $F(3,66) = 25.07$ ,  $p < .001$ ,  $MS_e = 29.83$ ) and sessions ( $F(2,44) = 3.57$ ,  $p < .05$ ,  $MS_e = 18.46$ ). The CM/VM and memory set interaction ( $F(3,66) = 4.18$ ,  $p < .001$ ) was also significant. However, none of the other interactions proved to be reliable. The main effect of memory set size reflects the expected performance decreases with increased memory set sizes. The CM/VM and memory set interaction reflects the previously noted trend for attenuation of memory set size effects in the CM versus VM condition.



**Figure 9-10.** Mean Percent Correct as a Function of Mapping Condition and Session.

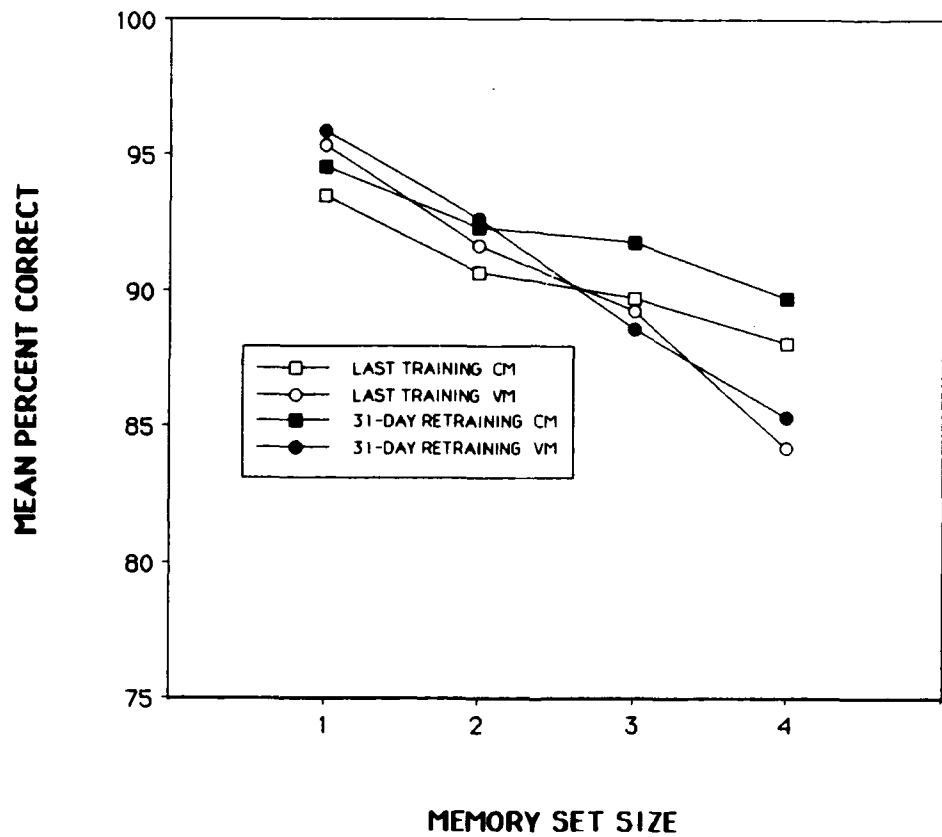
A Tukey HSD test was performed to investigate the significant main effect of sessions. The results showed that accuracy at the conclusion of the three-day retraining session was higher than at the conclusion of initial training.

Figure 9-11 depicts mean percent correct as a function of mapping condition and memory set size during the last training session and the last 31-day retraining test session. As demonstrated in the figure, memory set size affected performance in both mapping conditions but, once again, the decrements in performance associated with increased memory set size were less pronounced in the CM group than the VM group. As in the retention analysis, this difference is reflected in the mapping condition and memory set size interaction that proved reliable in the retraining analysis.

### Discussion

The results of this experiment indicate that over the three-day and 31-day retention intervals tested, no reliable losses in either CM or VM reaction time performance occurred. Relative to the three-day retention baseline, some slight loss of performance accuracy occurred at the 31-day interval, although there was no such loss relative to the last training session baseline. Therefore, the present results indicate that performance levels were essentially maintained within both mapping conditions over each of the retention intervals used. These results have important practical implication; they suggest that no retraining would be required over 31-day periods to maintain CM memory search performance at original levels under the training conditions in the current experiment.

The present results extend the work of Fisk et al. (1990) who reported no loss of CM performance over a 30-day interval in a pure memory search task with semantic category information, and Eggemeier et al. (1990) who reported similar results with static



**Figure 9-11.** Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Session.

spatial pattern information. Essentially the same result was obtained here in a memory search task with complex alphanumeric materials.

As noted above, the apparent improvement in VM performance over both retention intervals with respect to the last training session baseline can be attributed to the somewhat depressed performance levels exhibited by the VM group during the latter session. The reason for the somewhat depressed levels of performance cannot be determined on the basis of the present data. However, mild fatigue and the build-up of proactive interference within the two-hour training sessions may represent factors in the results. An important characteristic of automatic processing is its capability to insulate performance from the effects of some stressors (e.g., Fisk, Ackerman, and Schneider, 1987). Such insulation may be a factor in the failure to show depressed performance levels under the CM condition across two-hour training sessions.

Results of the retraining analyses indicate that, at both the three-day and 31-day retraining intervals, performance differences between CM and VM conditions were maintained. Also, performance levels in both groups met or actually exceeded comparable levels demonstrated during the last session of original training.

Experiment 10  
Retention of Complex Spatial Pattern Information  
in a Visual/Memory Search Task

Purpose

The purpose of this experiment was to investigate the retention of complex spatial pattern information in a visual/memory spatial search task of the type studied in Experiment 4. Eggemeier (1991) reported no loss of performance over a one-month retention interval with static spatial pattern information that represented the type of information processed by C<sup>2</sup> systems operators. The Eggemeier et al. (1991) work, conducted within a memory search task, indicated that no maintenance or refresher training would be required to maintain memory search performance over 30-day intervals with static spatial pattern information. However, Fisk et al. (1990, 1991), have reported differences in the retention of semantic information within visual/memory search and memory search paradigms that indicate that performance losses occurred in the former but not the latter type of search.

The Fisk et al. (1990, 1991) results demonstrated that differences in retention can occur with different search paradigms. They also indicated the importance of extending the Eggemeier et al. (1991) research to a visual/memory search paradigm. Consequently, a major purpose of the present experiment was to investigate the retention of automatic processing of spatial pattern information in this type of search paradigm.

Another purpose of this experiment was to investigate any retention differences that might be associated with variants in the type of original training. The same subjects who had previously served in Experiment 4 participated in this experiment. This afforded the opportunity to evaluate the effects of original whole-task versus part-task training on

retention over a one-month interval. Fisk et al. (1991) have evaluated the effect of a variant of a simplification part-task training procedure on the retention of semantic category information over a one-month interval in a visual/memory search task. Under retention conditions that did not distinguish target and distractor learning, there was no effect of original training type on retention. The present experiment investigated the applicability of this finding to spatial pattern information.

An additional issue concerned the effect of a short retraining period on performance levels under CM and VM mapping conditions following a one-month retention interval. The objective of a maintenance or refresher training program would be to eliminate any performance losses which might occur over a period of disuse. The intent of the present retraining period was to evaluate the effect of minimal additional training on performance following a one-month retention interval.

After a one-month interval, subjects who had participated in Experiment 4 completed two test sessions under whole-task conditions with the same spatial pattern materials trained in Experiment 4. Each session consisted of 200 trials; thus, a total of 400 test trials were completed by each subject.

To assess skill retention, the reaction time and response accuracy of the first 200 trials completed during the retention day were compared with the final test session data of the original training sessions. In a procedure similar to that employed in Experiment 9, the effect of a short retraining period was evaluated by comparing the last 200 trials of the retention session with the final test session of 200 trials that had been completed during original training.

## Method

Subjects. Subjects were the same 32 University of Dayton students who participated in Experiment 4. They were paid \$5.00/hour to participate.

Apparatus. The experiment was controlled and the data were collected by Zenith Z-248 computers with extended keyboards. Stimuli were presented on Z-1490 high-resolution, thirteen-inch color monitors.

Stimulus Materials. The same set of 16 spatial patterns that had served as stimuli for Experiment 4 were used in this experiment.

Procedure. Subjects performed the same visual/memory search task performed during Experiment 4. During each trial, subjects were shown a memory set of two to four spatial patterns on the computer CRT screen. The patterns comprising the memory set were selected at random from the entire stimulus pattern set within the VM condition, and from a subset of eight target patterns within the CM condition. The memory set remained on the screen until the subject pressed the return key on the computer keyboard.

The memory set was replaced with a test display that contained either two or four patterns. Each display included only one target and subtended a horizontal visual angle of approximately 6.9 degrees for a subject seated in the normal position with respect to the display. There were either one or three distractor patterns present in the test display. Patterns in the test display were arranged in quadrants. The subject was instructed to rapidly determine which pattern was a member of the previously presented memory set. Subjects indicated the location of the target pattern in a test quadrant by pressing a designated key on the numeric keyboard. The following keys were used to

represent each quadrant: the "four" key represented the upper left quadrant, the "five" key the upper right, the "one" key the lower left, and the "two" key the lower right. If the subject failed to respond within 3000 ms, the display was terminated and the system recorded a miss.

Memory set varied within a block of 20 trials; display set was blocked across sets of 20 trials. As in Experiment 4, blocking of the display set variable followed an ABBA counterbalancing procedure. Under this procedure, half the subjects first completed a block of trials under display set size two, followed by two blocks of trials under display set size four and a block of trials under display set size two. The opposite order of presentation (BAAB) was used for the remaining subjects.

Two dependent measures, reaction time and response accuracy, were recorded. Subjects were encouraged to respond as rapidly as possible while maintaining a high level of accuracy.

Feedback was identical to that in Experiment 4. After each trial, a message indicating whether the response was correct or incorrect appeared on the screen. The reaction time was given if the response was correct. At the end of each 20-trial block, the percent correct and mean reaction time over the 20 trials was shown. At the completion of a session, the percent correct and mean reaction time for the session were provided to the subject.

Subjects participated in this experiment one month after the completion of Experiment 4. Twenty-nine subjects were tested 31 days after completion of Experiment 4, and three subjects were tested 30 days after its completion. The current experiment consisted of two one-hour sessions that included ten 20-trial blocks. Therefore, subjects participated in a total of 400 trials (20 blocks of 20 trials).

All sessions during this experiment were conducted under whole-task conditions, such that all subjects within both CM and VM mapping conditions performed with the total stimulus set of 16 patterns employed in Experiment 4. Each CM subject continued with the same set of targets and distractors used previously. A major purpose of this experiment was to evaluate the effect of original part-task versus whole-task training on retention and retraining performance after a one-month period of disuse. Therefore, whole-task and part-task training designations from original training were carried forward to this experiment, even though all the present sessions were conducted under whole-task conditions. This resulted in four between-subjects original training conditions: (a) VM/WT, (b) VM/PT, (c) CM/WT, and (d) CM/PT. As in Experiment 4, there were eight subjects within each condition.

Design. Five independent variables were included in the design: (a) target/distractor mapping (CM versus VM); (b) original training condition (part-task training versus whole-task training); (c) display set size (2 or 4); (d) memory set size (2, 3, or 4); and (e) retention test sessions (1-2).

### Results

Retention Analyses. A  $2 \times 2 \times 3 \times 2 \times 2$  ANOVA was performed on the mean reaction time data from the last test session of 200 trials and the first test session of 200 trials during the one-month retention test. This analysis examined the effects of mapping condition (CM versus VM), original training type (whole-task versus part-task training), memory set size (2, 3, or 4), display set size (2 or 4), and sessions (last original training test session versus first retention test session). The ANOVA revealed that the main effects of mapping condition ( $F(1,28) = 72.85$ ,  $p < .001$ ,  $MS_e = 194675.13$ ), memory set size ( $F(2,56) = 93.60$ ,  $p < .001$ ,  $MS_e = 10615.75$ ), display set size ( $F(1,28) = 489.54$ ,  $p < .001$ ,  $MS_e = 20546.33$ ), and sessions

( $F(1,28) = 29.31, p < .001, MS_e = 23975.16$ ) were significant. The main effect of original training type ( $F(1,28) = 2.80, p > .05$ ) was not significant.

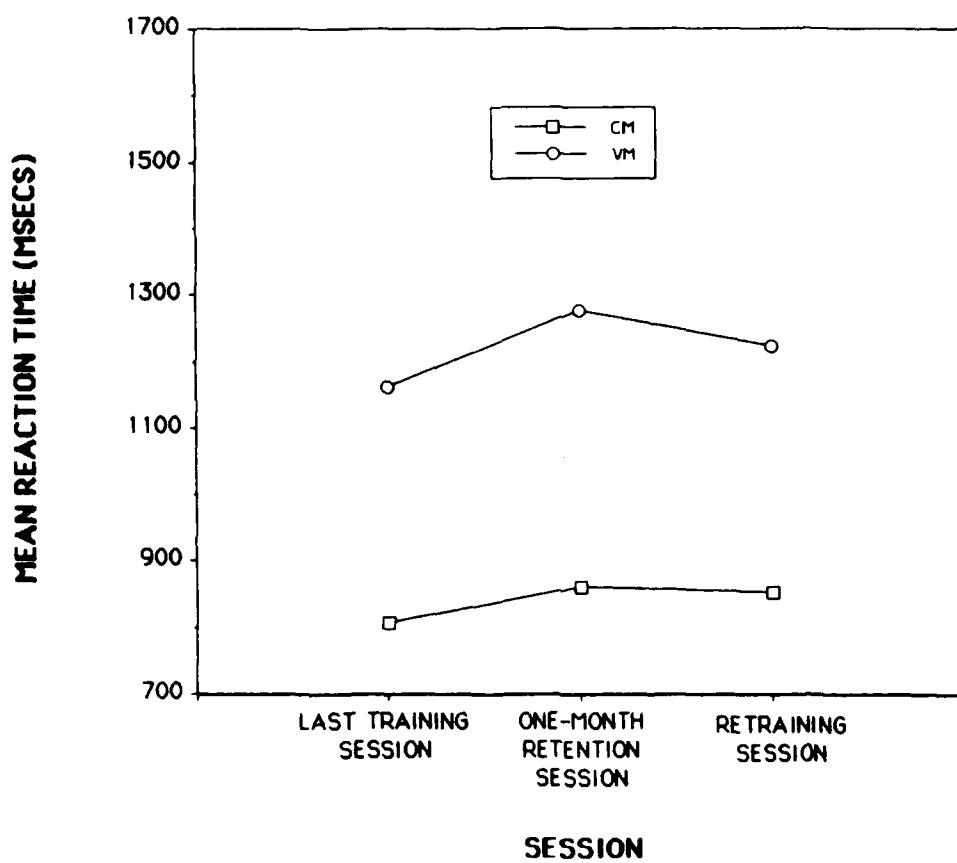
The ANOVA also showed that the memory and display set size interaction ( $F(2,56) = 9.32, p < .001, MS_e = 6668.53$ ), the mapping condition and memory set size interaction ( $F(2,56) = 45.21, p < .001$ ), and the mapping condition and display set size interaction ( $F(1,28) = 21.25, p < .001$ ) were reliable.

Significant three-way interactions were found for mapping condition, memory set size, and display set size ( $F(2,56) = 6.53, p < .01$ ), memory set size, sessions, and training type ( $F(1,28) = 5.02, p < 0.01$ ), and mapping condition, display set size, and training type ( $F(1,28) = 4.64, p < .05$ ). None of the other interactions proved to be reliable.

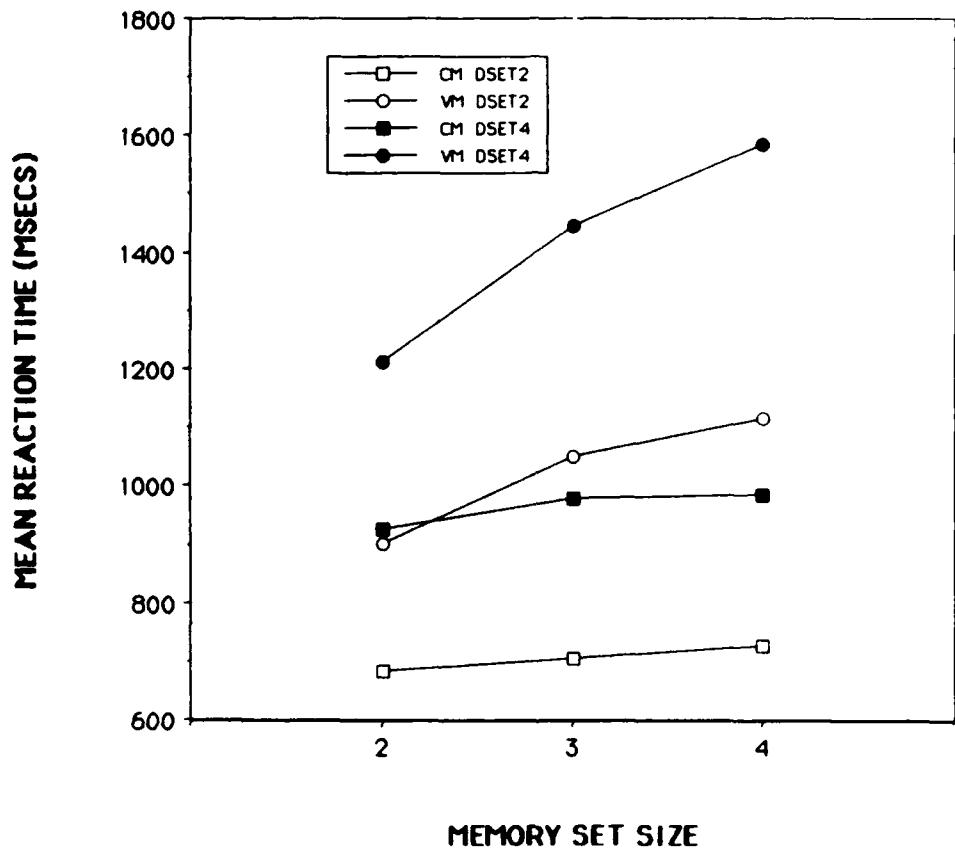
Figure 10-1 shows mean reaction time as a function of the last session of original training, the first (retention) session of the one-month retention test, and the second (retraining) session of the one-month retention test. There was some increase in mean reaction time between the last training session and the first retention session in both mapping conditions, but the CM group maintained its superiority across the one-month retention interval. The main effects of session and mapping conditions reflect this increase in reaction time and the superiority of the CM condition over the VM condition, respectively.

Figure 10-2 illustrates mean reaction time as a function of mapping condition, memory set size, and display set size in the retention analysis. As seen in the figure, both memory set and display set affected performance more markedly under the VM condition compared with the CM condition.

To investigate the three-way interaction of mapping condition, memory set size, and display set size, a  $3 \times 2$  ANOVA was conducted to investigate the effect of memory set size and



**Figure 10-1.** Mean Reaction Time as a Function of Mapping Condition and Session.

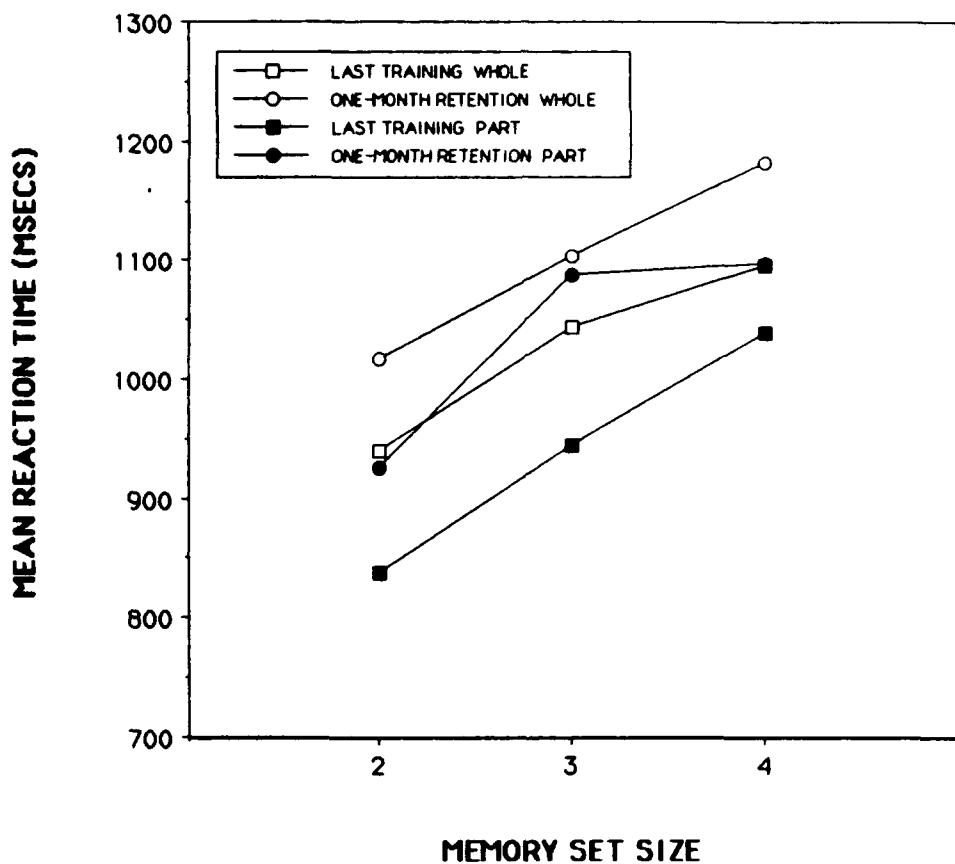


**Figure 10-2. Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Display Set Size.**

display set size at each mapping condition. This analysis showed that within the CM condition, the main effects of memory set size ( $F(2,56) = 4.38$ ,  $p < .05$ ,  $MS_e = 10615.75$ ) and display set size ( $F(1,28) = 153.40$ ,  $p < .001$ ,  $MS_e = 20546.33$ ) were reliable, but the memory set and display set interaction ( $F(2,56) = 0.51$ ,  $p > .05$ ,  $MS_e = 6668.53$ ) was not. Within the VM condition, the main effects of memory set size ( $F(2,56) = 134.42$ ,  $p < .001$ ) and display set size ( $F(1,28) = 357.39$ ,  $p < .001$ ) were significant, as was the display set size and memory set size interaction ( $F(2,56) = 15.34$ ,  $p < .001$ ).

The interaction of display set size and memory set size within the VM condition was investigated by performing tests of the main effect of memory set size at each display set size. These analyses showed that the effect of memory set size was reliable at both display set size two ( $F(2,56) = 111.81$ ,  $p < .001$ ,  $MS_e = 3452.71$ ) and size four ( $F(2,56) = 82.65$ ,  $p < .001$ ,  $MS_e = 13831.58$ ). As reflected in the  $MS_e$  values, the variability associated with the display set size four condition was approximately four times greater than that associated with the display set size two condition. Therefore, although the change in reaction time as a function of memory set was greater under the display set size four versus the display set size two condition, the  $F$  values do not reflect this basis for the noted interaction. These results indicate that within the retention analysis, the effects of display set size and memory set size were more marked under VM versus CM conditions. The two variables interacted to determine reaction time performance in the former but not the latter condition.

The three-way interaction of memory set, session, and original training type proved to be reliable in the overall ANOVA. Figure 10-3 shows mean reaction time as a function of memory set and training type in the last test session of training and the one-month retention test session. The effect of memory set tended to be very similar for both part-task and whole-task

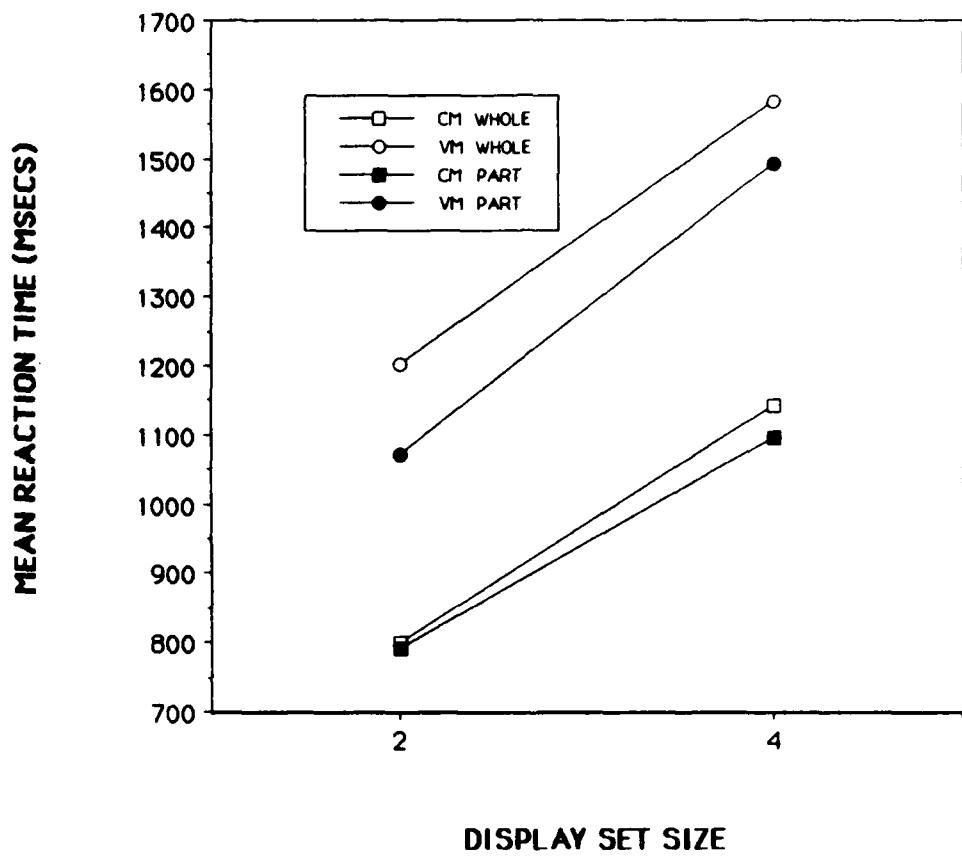


**Figure 10-3.** Mean Reaction Time as a Function of Training Type, Memory Set Size, and Session.

training conditions during the last training session. However, during the one-month retention test session, the part-task training group showed an increase in reaction time at memory-set size-three that appears disproportional to the increase within the whole-task training condition.

To follow up the significant three-way interaction, a  $2 \times 3$  ANOVA was conducted to test the effects of training type and memory set within the last training session and the one-month retention session. These analyses revealed no significant main effect of training type in the last training session ( $F(1,28) = 3.18, p > .05, MS_e = 112070.40$ ), a main effect of memory set size ( $F(2,56) = 65.63, p < .001, MS_e = 7707.40$ ), and no reliable interaction of training type and memory set size ( $F(2,56) = 1.30, p > .05$ ) within this session. Analyses conducted with the retention session data showed no main effect of training type ( $F(1,28) = 1.88, p > .05, MS_e = 106579.90$ ), but did demonstrate a significant main effect of memory set ( $F(2,56) = 63.17, p < .001, MS_e = 7740.03$ ) and a reliable memory set size and training type interaction ( $F(2,56) = 3.58, p < .05$ ). The basis of this interaction appears to have been the disproportionate increase in reaction time under memory set size three within the part-task training condition.

Figure 10-4 illustrates mean reaction time as a function of mapping condition, display set size, and training type. As shown in the figure, CM performance tended to be superior to VM performance under each condition, and the effect of display set size tended to be more pronounced in the VM versus the CM condition. It also appears that the effect of whole-task versus part-task training was somewhat more pronounced at display set size two than at display set size four under the VM condition. To evaluate the reliable three-way interaction that involved these variables, a  $2 \times 2$  ANOVA was conducted to investigate the effects of display set size and training type within the CM and VM mapping conditions.



**Figure 10-4.** Mean Reaction Time as a Function of Mapping Condition, Training Type, and Display Set Size.

Within the CM condition, the analysis showed that the main effect of display set size ( $F(1,28) = 153.40$ ,  $p < .01$ ,  $MS_e = 20546.33$ ) was reliable, but neither the main effect of training type ( $F(1,28) = 0.25$ ,  $p > .05$ ,  $MS_e = 194675.13$ ) nor the interaction of display set size and training type ( $F(1,28) = 1.12$ ,  $p > .05$ ) were reliable. A comparable analysis within the VM condition revealed that the main effect of display set size ( $F(1,28) = 357.39$ ) was significant, but failed to demonstrate either a reliable main effect of training type ( $F(1,28) = 3.47$ ,  $p > .05$ ) or a display set size and training type interaction ( $F(1,28) = 3.96$ ,  $p > .05$ ). Although neither of the latter two effects were reliable, the  $F$  values in each case approached those required for significance. Eta squared analyses showed that the effect of the display set size and training type interaction was more pronounced under the VM (.124) as opposed to the CM (.038) condition. This difference is reflected in the significant three-way interaction.

The results of the reaction time analysis demonstrate that some loss of performance occurred within both the CM and VM groups over the one-month retention interval. Although the interaction of mapping condition and sessions was not reliable, decrements in VM performance tended to be more pronounced than those in CM performance. CM performance maintained its advantage over VM performance across the retention interval, and the effects of memory set size and display set size tended to be greater under VM than CM conditions. There were no major effects of original part-task versus whole-task training on retention. The only reliable interaction involving original training type and sessions reflected a disproportionate increase in reaction time at memory set size three under part-task training at the one-month retention test.

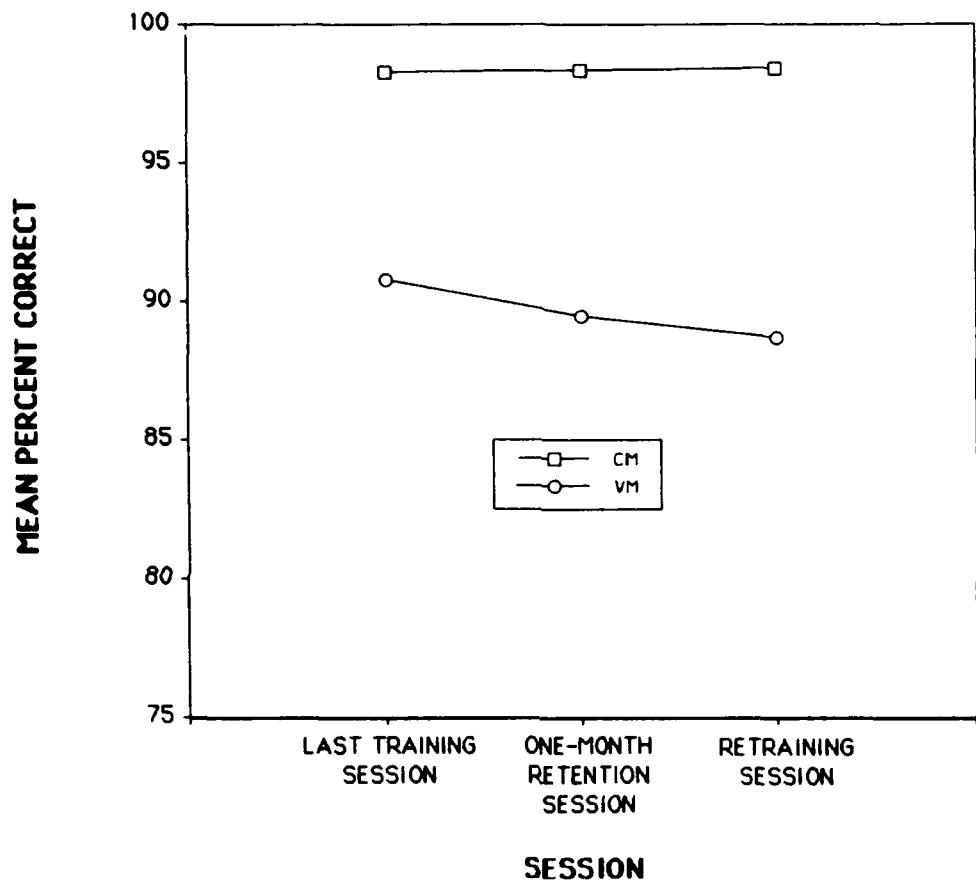
A  $2 \times 2 \times 3 \times 2 \times 2$  ANOVA, comparable to the reaction time analysis, was performed on the percent correct data to analyze the effects of mapping condition (CM versus VM), original

training type (whole-task versus part-task training), memory set size (2, 3, or 4), display set size (2 or 4), and sessions (last original training test session versus first retention test session). This analysis showed that the main effects of mapping condition ( $F(1,28) = 15.99$ ,  $p < .001$ ,  $MS_e = 376.66$ ), memory set size ( $F(2,56) = 21.85$ ,  $p < .001$ ,  $MS_e = 38.5$ ), and display set size ( $F(1,28) = 28.85$ ,  $p < .001$ ,  $MS_e = 41.37$ ) were significant. The main effects of original training type ( $F(1,28) = 1.85$ ,  $p > .05$ ) and sessions ( $F(1,28) = 0.44$ ,  $p > .05$ ,  $MS_e = 36.79$ ) did not prove to be reliable.

The interactions of memory set size and display set size ( $F(2,56) = 12.33$ ,  $p < .001$ ,  $MS_e = 16.25$ ), mapping condition and memory set size ( $F(2,56) = 16.83$ ,  $p < .001$ ), and mapping condition and display set size ( $F(1,28) = 26.51$ ,  $p < .001$ ) were reliable. The three-way interaction of mapping condition, memory set, and display set ( $F(2,56) = 10.35$ ,  $p < .001$ ) was also significant. There were no other significant interactions.

Figure 10-5 shows mean percent correct as a function of mapping condition in the last test session of training, the first (retention) one-month test session, and the second (retraining) one-month test session. As can be seen in the figure, CM performance maintained its superiority over VM performance across the retention interval; this is reflected in the main effect of mapping condition. While CM performance was maintained at the levels achieved during the last training session, VM performance showed a slight but nonsignificant tendency to deteriorate at the one-month retention test relative to the last training session.

Figure 10-6 illustrates mean percent correct as a function of memory set size, display set size, and mapping condition. Neither memory set size nor display set size markedly affected CM performance, but both variables influenced VM performance levels. In general, increases in both memory set size and display set size were associated with decreases in the accuracy of VM



**Figure 10-5.** Mean Percent Correct as a Function of Mapping Condition and Session.

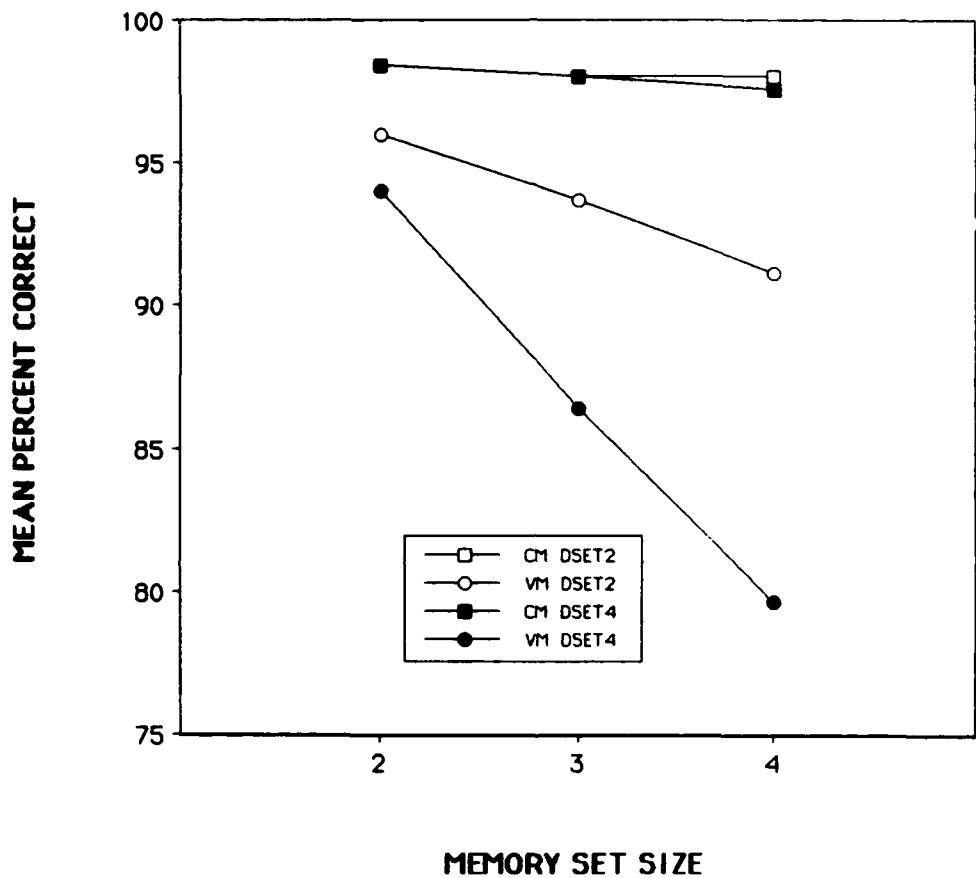


Figure 10-6. Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Display Set Size.

performance. The reliable three-way interaction of mapping condition, memory set, and display set was investigated through  $3 \times 2$  ANOVAs that were performed within the CM and VM conditions.

These analyses indicated that within the CM condition, the main effect of memory set size ( $F(2,56) = 0.17$ ,  $p > .05$ ,  $MS_e = 38.5$ ), the main effect of display set size ( $F(1,28) = 0.02$ ,  $p > .05$ ,  $MS_e = 41.37$ ), and the interaction of memory set size and display set size ( $F(2,56) = 0.06$ ,  $p > .05$ ,  $MS_e = 16.25$ ) were not reliable. However, within the VM condition the main effects of memory set size ( $F(2,56) = 38.51$ ,  $p < .001$ ) and display set size ( $F(1,28) = 55.34$ ,  $p < .001$ ) as well as their interaction ( $F(2,56) = 22.61$ ,  $p < .001$ ) were reliable.

To investigate the reliable memory set and display set interaction within the VM condition, tests of the main effect of memory set size were conducted within the display set size two condition and the display set size four condition. These analyses indicated that the effect of memory set size was reliable in both display set size two ( $F(2,56) = 10.08$ ,  $p < .001$ ,  $MS_e = 18.63$ ) and display set size four ( $F(2,56) = 46.03$ ,  $p < .001$ ,  $MS_e = 36.12$ ) conditions. Eta squared analyses showed that the effect of memory set was more pronounced within the display set size four condition (.622) than the display set size two condition (.265).

The results of the accuracy analysis parallel those of the reaction time analysis in demonstrating superiority of the CM condition versus the VM condition over the one-month retention interval. As in the reaction time analysis, both memory set size and display set size had a more pronounced effect on VM performance than CM performance. The retention accuracy analysis also failed to demonstrate any effect of original whole-task versus part-task training. Unlike the reaction time analysis that showed some one-month retention decrement under both mapping conditions, the present analysis did not demonstrate any loss in

the accuracy of performance over the one-month retention interval.

Retraining Analyses. Comparison of the second session of testing at the one-month retention interval with the last session of original training permits investigation of the effect of a relatively short retraining period on performance under CM and VM performance conditions. A  $2 \times 2 \times 3 \times 2 \times 2$  ANOVA was conducted to investigate the effect of mapping condition (CM versus VM), original training type (whole-task versus part-task training), memory set size (2, 3, or 4), display set size (2 or 4), and sessions (last original training test session versus second retention test session) on mean reaction time performance. This analysis revealed that the main effects of mapping condition ( $F(1,28) = 59.73, p < .001, MS_e = 211794.98$ ), memory set size ( $F(2,56) = 83.13, p < .001, MS_e = 11734.60$ ), display set size ( $F(1,28) = 467.55, p < .001, MS_e = 21727.04$ ), and sessions ( $F(1,28) = 10.71, p < .01, MS_e = 26377.09$ ) were reliable. Once again, the main effect of training type was not significant ( $F(1,28) = 2.03, p > .05$ ).

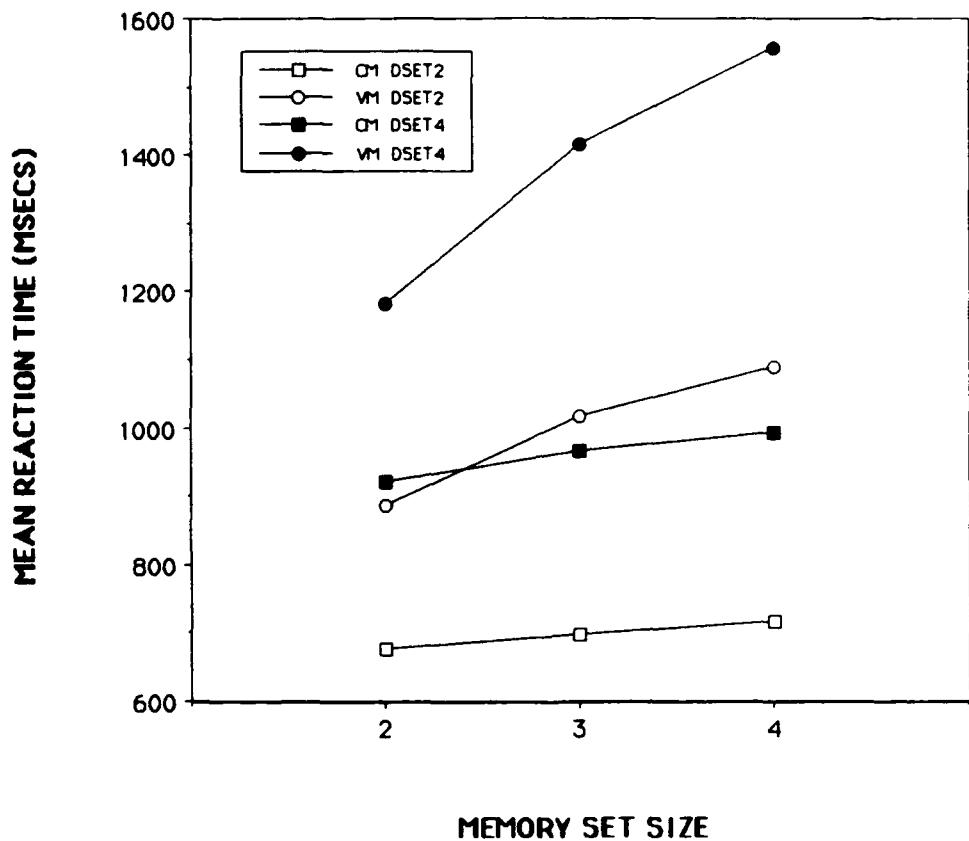
The interactions of memory set size and display set size ( $F(2,56) = 19.12, p < .001, MS_e = 4400.75$ ), mapping condition and memory set size ( $F(2,56) = 37.90, p < .001$ ), and mapping condition and display set size ( $F(1,28) = 17.38, p < .001$ ) also proved to be significant. The three-way interaction of mapping condition, memory set size, and display set size ( $F(2,56) = 9.0, p < .001$ ) was reliable as well. No other interactions were significant.

The previously described data from Figure 10-1 illustrate the basis of the main effects of mapping condition and sessions. They also show that during the retraining test session, CM performance was superior to VM performance, but reaction times under both mapping conditions were slower than in the last test session of original training.

Figure 10-7 illustrates mean reaction time as a function of mapping condition, memory set size, and display set size collapsed across the last training session and the retraining session of the retention test. As seen in the figure, the pattern in these data is very similar to that in the retention analysis. This shows that the effects of memory set size and display set size were less pronounced in the CM condition relative to the VM condition.

As a follow-up to the reliable three-way interaction, analyses were performed on the Figure 10-7 data to evaluate the effect of memory set and display set within the CM and VM conditions. These follow-up analyses showed that within the CM condition, the main effects of memory set size ( $F(2,56) = 4.39$ ,  $p < .05$ ,  $MS_e = 11734.60$ ) and display set size ( $F(1,28) = 152.31$ ,  $p < .001$ ,  $MS_e = 21727.04$ ) were reliable, but the interaction of memory set and display set ( $F(2,56) = 0.97$ ,  $p > .05$ ,  $MS_e = 4480.75$ ) was not.

Within the VM condition, the main effects of memory set size ( $F(2,56) = 116.64$ ,  $p < .001$ ) and display set size ( $F(1,28) = 332.62$ ,  $p < .001$ ) were significant, as was the interaction of display set and memory set ( $F(2,56) = 27.15$ ,  $p < .001$ ). To evaluate the display set and memory set interaction within the VM condition, tests of the main effects of memory set were conducted at each display set size. These analyses showed that the memory set effect was reliable at both display set size two ( $F(2,56) = 104.18$ ,  $p < .001$ ,  $MS_e = 3237.02$ ) and size four ( $F(2,56) = 88.85$ ,  $p < .001$ ,  $MS_e = 12978.33$ ). Once again, as reflected in the  $MS_e$  values, the variability associated with the display set size four condition was approximately four times greater than that associated with the display set size two condition. Consequently, although the change in reaction time as a function of memory set was greater under the display set size four versus the size two condition, the  $F$  values again do not



**Figure 10-7.** Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Display Set Size.

reflect this basis for the memory set and display set interaction.

The result of principal interest in this reaction time analysis was the reliable effect of sessions, which indicates that performance had not returned to original training baseline levels during the retraining session. Once again, original part-task versus whole-task training failed to reliably affect performance under either mapping condition. As in the retention analysis, higher levels of performance were demonstrated in the CM condition than in the VM condition. Memory set size and display set size continued to exert a more marked effect on VM performance than on CM performance.

A  $2 \times 2 \times 3 \times 2 \times 2$  ANOVA, comparable to the reaction time analysis, was performed on the percent correct response data from the last training test session and the second (retraining) session of the retention test. This analysis showed that the main effects of mapping condition ( $F(1,28) = 16.23, p < .001$ ,  $MSe = 412.32$ ), memory set size ( $F(2,56) = 18.66, p < .001$ ,  $MSe = 40.89$ ), and display set size ( $F(1,28) = 33.00, p < .001$ ,  $MSe = 38.0$ ) were reliable. The session main effect proved to be nonsignificant ( $F(1,28) = 3.05, p < .001$ ,  $MSe = 16.99$ ), as did the main effect of original training type ( $F(1,28) = 1.81, p > .05$ ).

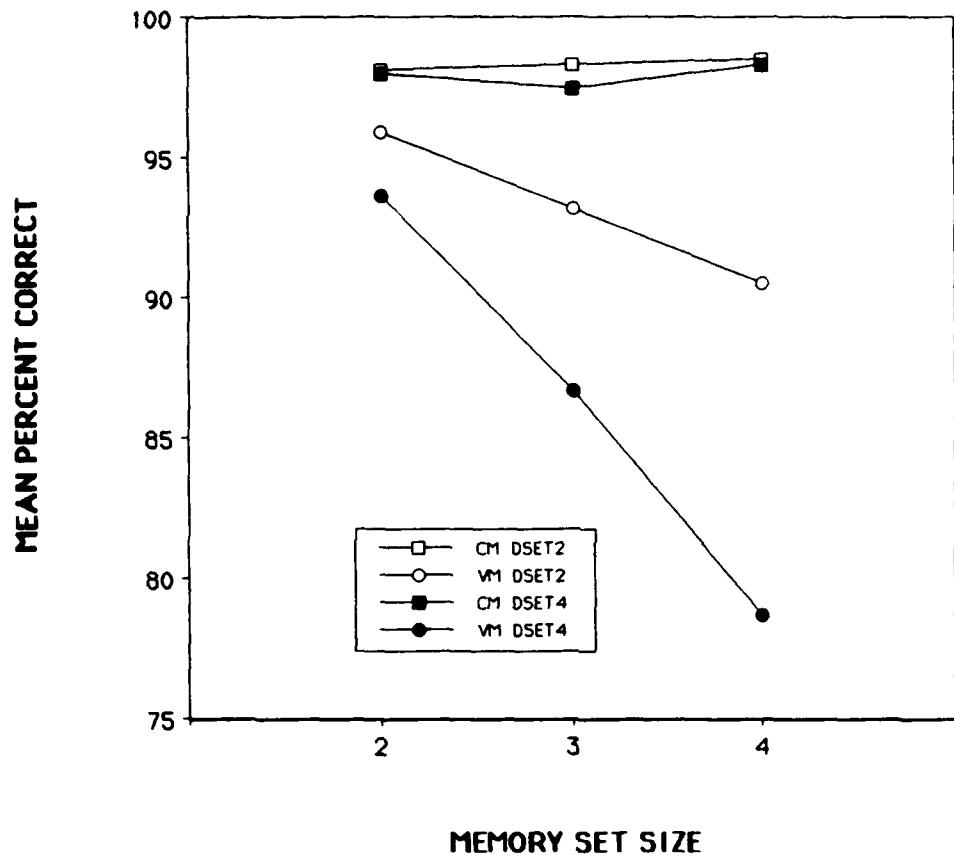
The interactions of memory set size and display set size ( $F(2,56) = 8.84, p < .001$ ,  $MSe = 20.57$ ), mapping condition and memory set size ( $F(2,56) = 21.85, p < .001$ ), mapping condition and display set size ( $F(1,28) = 26.60, p < .001$ ), and mapping condition and sessions ( $F(1,28) = 10.77, p < .01$ ) also proved to be significant. The ANOVA demonstrated that the three-way interactions of mapping condition, memory set size, and display set size ( $F(2,56) = 8.91, p < .001$ ) and display set size, mapping condition, and training type ( $F(1,28) = 5.33, p < .05$ ) were significant. No other interactions were reliable.

The data shown in Figure 10-5 illustrate the basis for the main effect of mapping condition, and show that the CM group maintained its superiority over the VM group across the training and retraining sessions. The figure also shows that while the CM group appears to have maintained its performance levels across the training and retraining sessions, there was a decrement in VM performance in the retraining session relative to the last original training session.

To investigate the significant interaction of mapping condition and sessions, tests of the effect of sessions were conducted within the CM and VM conditions. These analyses showed that, as expected, there was no reliable sessions effect within the CM condition ( $F(1,28) = 1.18$ ,  $p > .05$ ,  $MS_e = 16.99$ ), but the effect of sessions was significant within the VM condition ( $F(1,28) = 12.64$ ,  $p < .005$ ). Therefore, there was a reliable decline in performance within the VM condition from the last original training session to the retraining session.

Figure 10-8 shows mean percent correct as a function of mapping condition, memory set size, and display set size in the retraining analysis. This pattern, very similar to that noted in the retention analysis, shows that both memory set size and display set size had more pronounced effects on performance under VM versus CM mapping conditions. To evaluate the three-way interaction of mapping condition, memory set size, and display set size, analyses were performed to investigate the effect of memory set size and display set size within the CM and VM conditions.

These analyses revealed that within the CM condition, neither the main effect of memory set size ( $F(2,56) = 0.12$ ,  $p > .05$ ,  $MS_e = 40.89$ ) nor display set size ( $F(1,28) = 0.13$ ,  $p > .05$ ,  $MS_e = 38.00$ ) was significant. Also, the interaction of memory set size and display set size ( $F(2,56) = 0.13$ ,  $p > .05$ ,



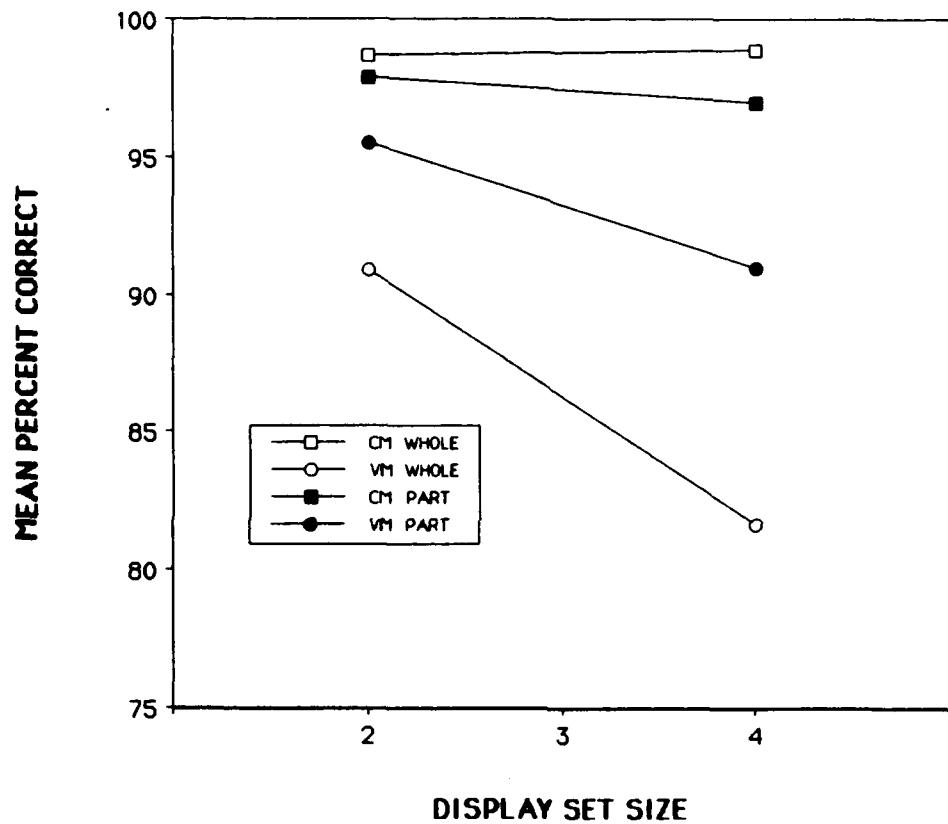
**Figure 10-8.** Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Display Set Size.

$MS_e = 20.57$ ) was nonsignificant. Within the VM condition, the main effect of memory set size ( $F(2,56) = 40.39, p < .001$ ), the main effect of display set size ( $F(1,28) = 59.52, p < .001$ ), and their interaction ( $F(2,56) = 17.62, p < .001$ ) proved to be significant.

The memory set and display set interaction within the VM condition was evaluated through tests of the main effect of memory set within the display set size two and size four conditions. These analyses indicated that the effect of memory set size was reliable in both the display set size two ( $F(2,56) = 17.61, p < .001, MS_e = 13.28$ ) and size four ( $F(2,56) = 36.95, p < .001, MS_e = 48.18$ ) conditions. Eta squared analyses showed that the effect of memory set was more pronounced within the display set size four condition (.568) than the size two condition (.368).

Figure 10-9 shows mean percent correct as a function of mapping condition, training type, and display set size. As seen in the figure, display set size had relatively little effect on percent correct under both whole-task and part-task CM conditions. However, display set size had a more marked effect on VM performance, particularly under whole-task training. The reliable three-way interaction of mapping condition, display set size, and training type was investigated through an analysis of display set size effects and training type within the CM and VM conditions. The CM analysis showed that the main effects of training type ( $F(1,28) = 0.22, p > .05, MS_e = 412.32$ ), display set size ( $F(1,28) = 0.18, p > .05, MS_e = 38.00$ ), and their interaction ( $F(1,28) = 0.43, p > .05$ ) were not reliable. Within the VM condition, the main effects of training type ( $F(1,28) = 5.62, p < .05$ ), display set size ( $F(1,28) = 59.52, p < .001$ ), and their interaction ( $F(1,28) = 6.94, p < .001$ ) were significant.

The reliable interaction of display set size and training type was followed by an analysis of the display set size effect



**Figure 10-9.** Mean Percent Correct as a Function of Mapping Condition, Training Type, and Display Set Size.

at each level of training type. These analyses showed that the effect of display set was significant within both the whole-task training condition ( $F(1,14) = 28.93$ ,  $p < .001$ ) and within the part-task training condition ( $F(1,14) = 6.97$ ,  $p < .05$ ). Eta squared analyses showed that the effect of display set size was more pronounced under whole-task (.673) versus part-task (.333) training conditions.

The results of the accuracy analysis generally parallel the results of the reaction time analysis and demonstrate superior performance within the CM condition compared to the VM condition. There were no differences in CM performance accuracy between the original training baseline session and the retraining session, but VM performance showed a reliable decline across these sessions. As in the reaction time analysis, memory set size and display set size had greater effect on VM than CM performance. Original part-task versus whole-task training had no effect on CM performance. However, original whole-task training was associated with a more marked effect of display set size on VM performance than was part-task training in this analysis. The Experiment 4 accuracy analysis had shown a similar result of whole-task versus part-task training on memory set size effects within the VM condition, but had not shown the present display set size effect.

### Discussion

This experiment demonstrated a reliable increase in reaction time performance in both the CM and VM conditions across the one-month retention interval. Coupled with the Eggemeier et al. (1991) data that showed no reliable effect of a similar interval on static pattern information processing within a memory search paradigm, the present results suggest that retention can vary as a function of the type of search task which is performed. Therefore, the current data and those of Eggemeier et al. (1991) are consistent with the results of Fisk et al. (1990, 1991) which

demonstrated that retention losses within a visual/memory search paradigm exceeded those associated with either pure memory search or visual search. Within the present experiment, statistically equivalent performance losses were obtained under CM and VM conditions. This, in turn, suggests that the performance losses observed may not have been specific to the automatic processing originally established within the CM condition.

The present results have important implications for refresher training programs intended to maintain baseline performance levels, and indicate that some training would be required over thirty-day intervals to maintain reaction time performance. It is important to note that these recommendations pertain to the type of visual/memory search functions employed in the present experiment and do not apply to the maintenance of performance under memory search conditions of the type investigated by Eggemeier et al. (1991).

The current data also indicate that short retraining periods of the type used here were not sufficient to return reaction time performance to training baseline levels. The present results do not permit specification of the amount of training required to re-achieve baseline levels. Future research to support the development of C<sup>2</sup> operator training should address this issue.

As in the Experiment 4 data that pertained to acquisition of automatic processing, the present results demonstrated no major effect of original whole-task versus part-task training on retention under the CM condition. Part-task training effects were limited to performance under one memory set size in the retention analysis and to the effect of display set size on the accuracy of VM performance in the retraining analysis. Therefore, the current data are consistent with those of Fisk et al. (1991), who reported no retention effect of whole-task versus part-task training under task performance conditions similar to the present paradigm, which reflected the effects of both target

and distractor item learning. Thus, the current results generally parallel the pattern of the acquisition analysis reported in Experiment 4 and provide no basis to recommend the use of the present part-task training procedure as a means of improving retention under either CM or VM conditions.

#### Experiment 11

#### Retention of Automatic Processing in a Visual/Memory Search Task Requiring the Processing of Rule-Based Alphanumeric Information

##### Purpose

The purpose of this experiment was to investigate automatic processing retention in a visual/memory search task that required the processing of rule-based alphanumeric information. Because of the critical role played by this type of information in many Air Force C<sup>2</sup> systems, it was considered important to extend previous retention work (e.g., Eggemeier et al., 1991; Fisk et al., 1990, 1991) with semantic category search and spatial pattern search to a visual/memory search task that involved the processing of rule-based alphanumeric information.

Experiment 9 had shown no appreciable loss of information over 31-day retention intervals with complex alphanumeric information. However, that experiment did not require the conjunction of two information elements in the form of a rule, and it involved memory search as opposed to visual/memory search. Experiment 10 demonstrated reliable decrements in reaction time performance over a one-month retention interval in a visual/memory search paradigm with spatial pattern information. An earlier experiment (Eggemeier et al., 1991) showed no such decrement with similar spatial pattern information within a memory search task.

Therefore, the present experiment was performed to investigate the retention of rule-based alphanumeric materials in a visual/memory search task that was the same as the one used during Experiments 2 and 6. In addition to assessing the speed and accuracy of performance, this experiment investigated the effect of a retention interval on the subjective workload associated with task performance. Once again, the NASA TLX (Hart and Staveland, 1988) was used to assess the workload imposed by the visual/memory search task.

Retention in the present experiment was tested after a 26-day interval. This interval closely approximated the one-month intervals used in the previous experiments in this series and permitted some comparison of the current results with those of earlier experiments.

#### Method

Subjects. Subjects were the same eight University of Dayton students who had participated in Experiments 2 and 6. They were paid \$3.75/hour, plus a \$1.25/hour bonus for prompt attendance.

Apparatus. The experiment used the same type of Zenith Data Systems 248 computer and Zenith ZCM-1490 high-resolution, thirteen-inch color monitor used in Experiment 2. Responses were made on the same numeric keys of a standard expanded IBM-compatible keyboard used in the previous two experiments.

Procedure. Subjects performed the same type of visual/memory search task trained in Experiment 2. The same target/distractor mappings (CM versus VM) were also employed. During each trial, subjects were presented with a memory set of one to four alphanumeric rules that remained on the CRT screen until the subject pressed a designated key. These rules, the same type used in Experiment 2, consisted of the conjunction of a three-letter sequence and a range of numerical values. After

presentation of the memory set, a test display consisting of four test items arranged in a quadrant was presented until either the subject responded or 5 seconds elapsed. Individual test items, the same type as used in Experiment 2, consisted of a three-letter sequence and a single two-digit numeral.

As in Experiment 2, subjects determined which of the four test items represented an exemplar of one of the rules presented in the memory set and responded by pressing the appropriate numeric key to indicate the spatial position of the critical test item within the test display quadrant. An exemplar of one of the memory set rules was present in each trial. As in Experiment 2, there were three non-target or distractor exemplars for each trial. In half the trials, one of these distractors represented a non-target instance of one of the rules that had appeared in the memory set; the remaining two distractors represented instances of rules which had not appeared in the memory set. For the remaining trials, two of these distractors represented instances of a single rule which had not appeared in the memory set; the third distractor represented an additional non-memory set rule. This procedure was intended to preclude a subject from responding correctly at required levels across trials on the basis of either single component (i.e., three-letter sequence, numerical value) of the rules. Both reaction time and accuracy measures were collected. Subjects were instructed to maintain the same 90-percent criterion level used in Experiment 2.

NASA TLX workload ratings were completed by subjects at the end of each session. Subjects rated the workload associated with performance of the visual/memory search task under both CM and VM conditions through use of standard TLX procedures. These procedures required the completion of separate ratings for each of the six TLX dimensions. Subjects first rated the last block of trials, then provided ratings on the next-to-last block of trials. Therefore, half the subjects rated the CM condition

followed by the VM condition, while the remaining subjects rated the VM condition first and the CM condition second.

Visual feedback was provided to subjects in the same format as in Experiment 2. After each trial, an incorrect response was followed by an "Incorrect Response" message and the reaction time for the trial. A correct response was followed by a "Correct Response" message and the reaction time for that trial.

Summary feedback, presented at the completion of each block of trials, provided mean reaction time and accuracy performance levels from the trial block just completed. Summary feedback concerning mean reaction times and accuracy levels was also provided to subjects at the completion of each session. A written tally of mean reaction time and accuracy levels across blocks of trials was maintained by subjects as an aid in monitoring progress across sessions.

Subjects in this experiment had previously participated in both Experiments 2 and 6; therefore, each subject had completed 3200 trials of original training and 640 trials of transfer prior to the present experiment. Because the transfer trials intervened between the completion of original training and this experiment, subjects completed one additional acquisition session of 320 trials in the present experiment under the same conditions originally trained. The purpose of this additional acquisition session was to provide a training baseline for the assessment of retention effects. Twenty-six days following this baseline training session, subjects returned to the laboratory for a retention test session that involved the same rules and procedures utilized during both original training and the training baseline session. Thus, subjects had received a total of 3520 acquisition trials on the rules to be retained over the twenty-six day interval.

The retention session for all subjects consisted of one session of eight 40-trial blocks, for a total of 320 retention trials. Prior to the start of actual data collection during the retention session, subjects participated in two blocks of warm-up trials that required the search for single digits in a visual/memory search task using the same type of test display arrangement and response keys as in subsequent testing of rule retention. One block of warm-up trials was performed under CM conditions; the other was performed under VM conditions. The purpose of these warm-up trials was to re-familiarize subjects with the procedures of the experiment through visual/memory search for digit materials unrelated to the rules to be tested.

Design. Three within-subjects variables were included in the design: (a) mapping condition (CM versus VM), (b) memory set size (1-4), and (c) sessions (training baseline versus retention test).

### Results

Reaction Time Analyses. Figure 11-1 depicts mean reaction time as a function of mapping condition, memory set size, and sessions (training baseline versus retention test). Reaction times are based upon correct responses. As shown in the figure, reaction times in the retention session were somewhat higher than in the training baseline session; this was true under both mapping conditions. The effect of memory set size tended to be attenuated in the CM condition relative to the VM condition. This attenuation remained quite stable over the retention interval. Slopes of the functions relating reaction time to memory set size were 218 ms and 244 ms under CM conditions during the training baseline and retention sessions, respectively. Comparable slopes within the VM condition were 444 ms and 464 ms.

A 2 x 4 x 2 ANOVA was conducted on these data to investigate the effects of mapping condition (CM versus VM), memory set size,

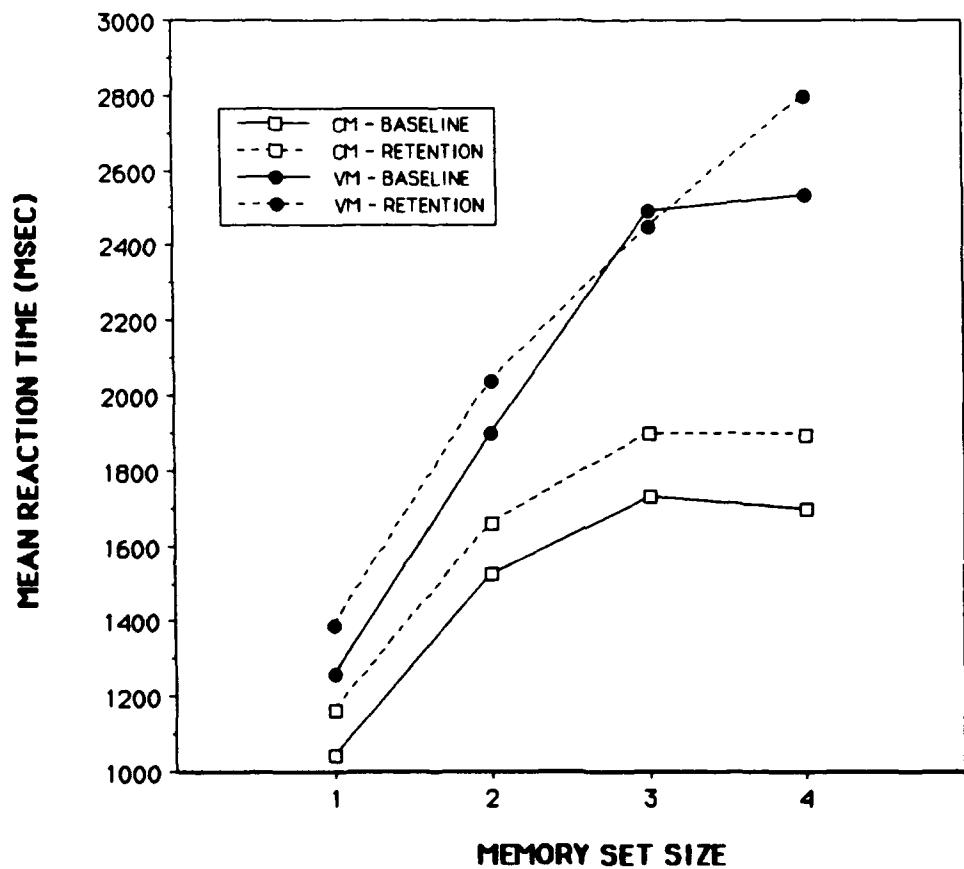


Figure 11-1. Mean Reaction Time as a Function of Mapping Condition, Memory Set Size, and Session.

and sessions (training baseline versus retention test) on reaction time performance. This analysis indicated that the main effects of mapping condition ( $F(1,7) = 57.52, p < .001$ ,  $MS_e = 156407.90$ ), memory set size ( $F(3,21) = 68.22, p < .001$ ,  $MS_e = 100615.17$ ), and sessions ( $F(1,7) = 8.33, p < .05$ ,  $MS_e = 73609.59$ ) were significant. In addition, the mapping condition and memory set size interaction ( $F(3,21) = 14.70, p < .001$ ,  $MS_e = 45715.61$ ) was significant. None of the other interactions proved to be reliable.

The significant interaction reflects the greater attenuation of the CM versus the VM memory set size effect illustrated in Figure 11-1. To investigate the significant interaction, tests of the memory set effect were conducted within the CM and VM conditions. These analyses indicated that the effect of memory set was significant in both the CM ( $F(3,21) = 32.09, p < .001$ ,  $MS_e = 54913.21$ ) and VM ( $F(3,21) = 63.16, p < .001$ ,  $MS_e = 91417.57$ ) conditions. Eta squared analyses indicated that, as expected, the size of the memory set effect was greater in the VM (.900) than the CM (.821) condition.

The results of the reaction time analysis indicate that, although there was a significant loss of performance across the retention interval, overall differences in reaction time between the CM and VM conditions were maintained. The attenuation of the memory set size effect was also maintained within the CM versus the VM condition.

Response Accuracy Analyses. Figure 11-2 shows mean percent correct as a function of mapping condition and memory set size in the training baseline and retention test sessions. As depicted in the figure, the CM condition tended to be associated with higher accuracy levels than the VM condition, particularly at the larger memory set sizes. There was also no marked trend for losses in accuracy from the training baseline to the retention test sessions.

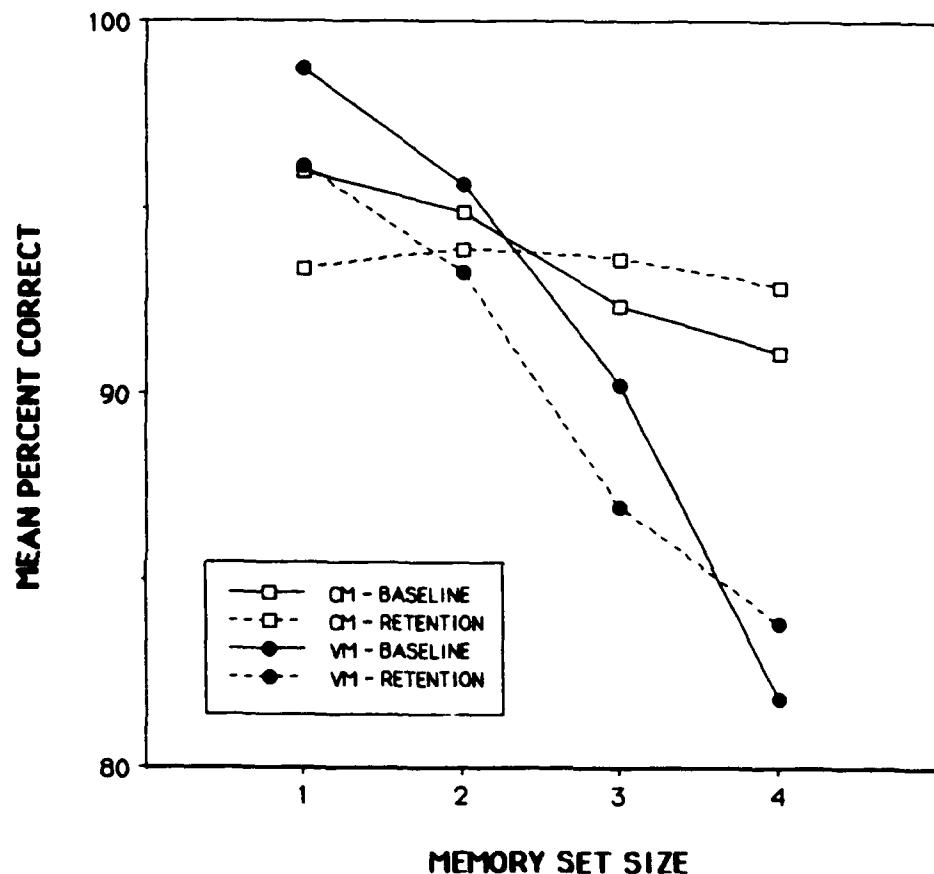


Figure 11-2. Mean Percent Correct as a Function of Mapping Condition, Memory Set Size, and Session.

A 2 x 4 x 2 ANOVA, comparable to the reaction time analysis, was conducted on the percent correct data to investigate the effects of mapping condition, memory set size, and sessions (training baseline versus retention test) on percent correct performance. This analysis showed that the main effects of mapping condition ( $F(1,7) = 23.35$ ,  $p < .005$ ,  $MS_e = 9.78$ ) and memory set size ( $F(3,21) = 14.80$ ,  $p < .001$ ,  $MS_e = 31.99$ ) were significant, but that the effect of sessions ( $F(1,7) = 1.07$ ,  $p > .05$ ,  $MS_e = 22.01$ ) was not. As in the reaction time analysis, the interaction of mapping condition and memory set was significant ( $F(3,21) = 6.73$ ,  $p < .005$ ,  $MS_e = 32.24$ ). However, none of the other interactions proved to be reliable.

Once again, the interaction of mapping condition and memory set size reflects a greater attenuation of the memory set size effect within the CM versus the VM condition. To investigate the significant interaction, tests of the memory set effect were conducted within the CM and VM conditions. These analyses showed that the effect of memory set was significant in the VM condition ( $F(3,21) = 13.88$ ,  $p < .001$ ,  $MS_e = 47.95$ ) but not in the CM condition ( $F(3,21) = 1.53$ ,  $p > .05$ ,  $MS_e = 16.28$ ).

The results of the accuracy analyses paralleled the reaction time analyses by indicating that the superiority of CM performance was maintained over the retention interval, as was the greater attenuation of memory set size effects in the CM condition relative to the VM condition. However, the accuracy analysis failed to demonstrate a significant sessions effect, indicating no loss in the performance accuracy over the one-month retention interval.

Workload Rating Analyses. Figure 11-3 depicts mean NASA TLX workload ratings as a function of mapping condition and sessions (training baseline versus retention test). Workload ratings illustrated in Figure 11-3 are based upon overall TLX workload ratings, which were derived by combining weighted ratings on the

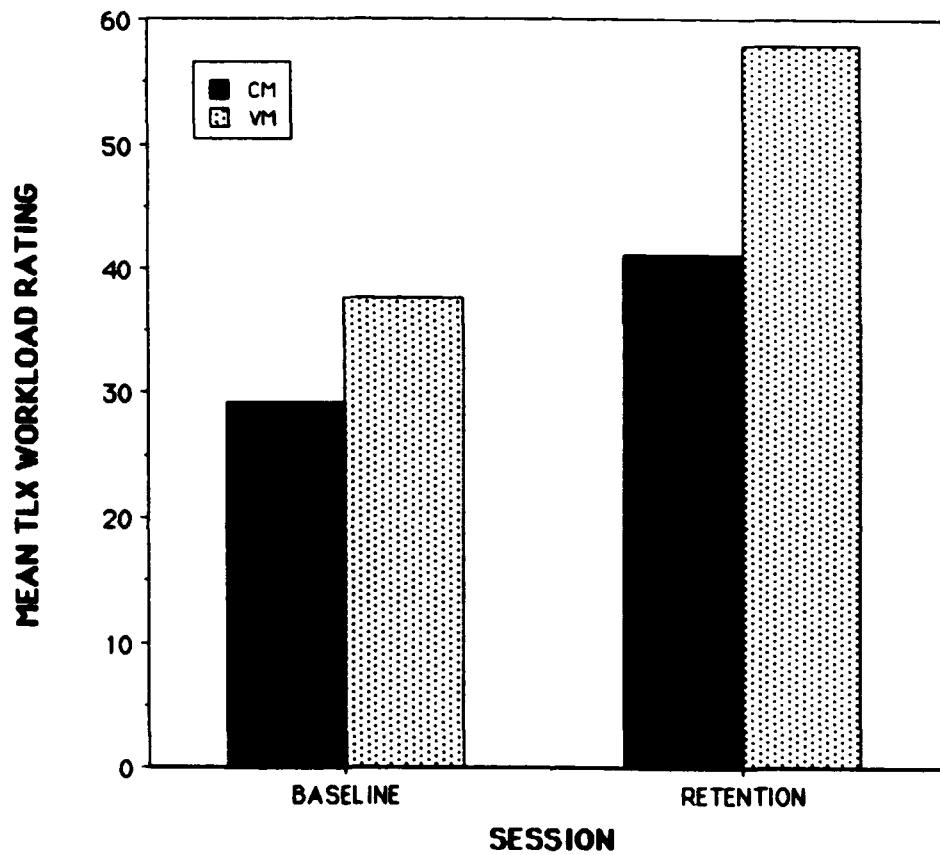


Figure 11-3. Mean TLX Workload Rating as a Function of Mapping Condition and Session.

six TLX dimensions. There was some trend for rated workload to increase from the training baseline to the retention session. This increase occurred in both the CM and VM conditions, but tended to be somewhat more pronounced in the VM condition.

A 2 x 2 ANOVA was performed on the data shown in Figure 11-3 in order to evaluate the effects of mapping condition and sessions (training baseline versus retention test) on rated workload. This analysis indicated that the main effects of mapping condition ( $F(1,7) = 20.21$ ,  $p < .005$ ,  $MS_e = 63.71$ ) and sessions ( $F(1,7) = 7.53$ ,  $p < .05$ ,  $MS_e = 274.10$ ) were significant. The interaction of mapping condition and sessions ( $F(1,7) = 5.47$ ,  $p > .05$ ,  $MS_e = 25.64$ ) was not reliable, although the  $F$  value approached that required for significance.

The results of the workload analysis indicate that, although there was a reliable increase in the subjective workload associated with performance of the visual/memory search task over the retention interval, the reliably lower levels of workload associated with the CM versus the VM condition remained. In fact, although the interaction of sessions and mapping condition was not reliable, there was some trend for the CM versus VM workload difference to increase over the retention interval.

### Discussion

The results of the present study indicate that with rule-based alphanumeric materials, there was a reliable decrement in reaction time performance over the 26-day retention interval in the visual/memory search task. This slowing occurred under both CM and VM conditions, and the CM condition maintained its superiority over the VM condition across the retention interval. There was no effect of retention interval on performance accuracy.

These reaction time results are consistent with the pattern of results obtained in Experiment 10. In contrast to the present results and those of Experiment 10, the results of Experiment 9 showed no reliable loss of alphanumeric information over a one-month retention interval in a memory search task. Previously reported work with static spatial pattern information (Eggemeier et al., 1991) also failed to show significant decrements in performance over a one-month period in a memory search task.

Work to date in this program has demonstrated no reliable performance losses in either CM or VM conditions over one-month intervals with memory search tasks, but has demonstrated significant losses under both types of mapping conditions in visual/memory search. Fisk et al. (1990, 1991) have reported similar results with the retention of semantic information in memory search versus visual/memory search paradigms. Therefore, the pattern of results suggests that the type of task performed may have an important impact on retention interval effects. It also indicates that this is a variable that should be considered in the development of training programs for Air Force C<sup>2</sup> operators.

The present experiment also demonstrated some increase in the workload associated with task performance over the retention interval tested. This effect was obtained under both mapping conditions, although there was a nonsignificant trend for VM workload increases to be somewhat more pronounced than CM increases. The increase in rated workload is potentially important because workload can affect critical elements of operator performance, such as timesharing capability.

It is important to note that this study did not directly test the implications of increased subjective workload for timesharing efficiency, although some investigators (e.g., Reid et al., 1981) have reported significant correlations between workload ratings and concurrent task performance. Thus, the

increase in rated workload over the retention interval represents an important area for future research that is directed toward applications to Air Force C<sup>2</sup> operator training.

#### Summary and General Discussion

The present series of experiments examined the retention of automatic processing of alphanumeric information in both memory and visual/memory search paradigms. It also evaluated the retention of spatial pattern information within a visual/memory search paradigm.

Experiment 9 demonstrated no reliable effect of a 31-day retention interval for three-letter sequences within a memory search paradigm. Thus, it paralleled earlier research performed by Eggemeier et al. (1991) with static spatial pattern information. In contrast to these results, Experiment 11 demonstrated a small but reliable decrement in reaction time performance across a similar retention interval with complex alphanumeric information in a rule-based visual/memory search task.

The present results do not permit identification of the precise factor(s) responsible for the discrepancy in the results of Experiments 9 and 11 because both the type of search task (memory search versus visual/memory search) and the complexity of the to-be-processed information (letter sequences versus conjunction of letter sequences and numerical values) differed between the experiments. However, on the basis of the Fisk et al. (1990, 1991) results, it can be hypothesized that the type of search paradigm was at least a partial contributor to the noted differences in retention performance. Evaluation of retention performance in a rule-based task under memory search conditions would provide the additional data necessary for a more complete evaluation of the responsible factor(s); it therefore represents an important direction for future research.

In addition to demonstrating differences in reaction time performance under both mapping conditions over a 26-day retention interval, Experiment 11 demonstrated a reliable increase in the workload associated with performance under both CM and VM conditions over the interval. This increase is of considerable potential relevance to operator timesharing performance within C<sup>2</sup> systems and represents an important area for future research. It has been maintained (e.g., Eggemeier and Wilson, 1991) that workload can increase over certain ranges without decrements in task performance. Therefore, it is also important to evaluate the workload associated with retention intervals that have failed to produce reliable task performance decrements within memory search paradigms (Eggemeier et al., 1991; Fisk et al., 1990, 1991).

Experiment 10 evaluated the effect of a one-month retention interval on performance with spatial pattern information within a visual/memory search paradigm. It also showed a reliable decrement in reaction time performance over that interval. As noted above, Eggemeier et al. (1991) reported no loss of performance over a similar interval with spatial pattern information within a memory search paradigm. Therefore, it would appear that the difference in search paradigms between the two experiments constitutes a major factor in the discrepant results. This conclusion, consistent with the data of Fisk et al. (1990, 1991), suggests that the type of search function is a critical variable that should be considered in the design of maintenance/refresher training programs for C<sup>2</sup> systems operators.

Experiment 10 also demonstrated that original part-task versus whole-task training had no major effect on retention under either CM or VM conditions. These results are also consistent with those obtained by Fisk et al. (1991) under similar task performance conditions with semantic information within a visual/memory search paradigm. The results of Experiment 10

indicate that the variant of part-task versus whole-task training employed in the present study does not constitute a factor that should be considered in the design of training programs intended to maintain automatic processing of spatial pattern information over one-month periods of disuse.

#### V. WORKLOAD AS INDEXED BY DUAL-TASK PERFORMANCE UNDER AUTOMATIC AND CONTROLLED PROCESSING CONDITIONS

A principal characteristic of automatic processing is a reduction in the information processing resources necessary for task performance. Such reductions in workload or resource expenditure are of great potential importance to C<sup>2</sup> systems operators. Processing resources not required to perform an automatized task component can be allocated to concurrent tasks that require the same type of resources. Allocation of these resources to concurrent tasks can improve the capability of the operator to perform such tasks, thereby increasing timesharing performance.

The expected increases in timesharing levels with automatic processing have been demonstrated in a number of instances (e.g., Fisk and Lloyd, 1988; Fisk and Schneider, 1983; Schneider and Fisk, 1982, 1984; Strayer and Kramer, 1990; Venturino, 1991) in which CM tasks have been performed at high levels of efficiency with concurrent VM tasks. With few exceptions (e.g., Fisk and Lloyd, 1988; Venturino, 1991), previous work has centered on timesharing in tasks that involve the processing of alphanumeric or semantic information rather than spatial information. Therefore, evaluation of the workload associated with processing information representative of that found in C<sup>2</sup> systems is an important area for research intended to support applications of automatic processing to C<sup>2</sup> operator performance.

Experiments 2 and 3 investigated the subjective workload associated with performance of visual/memory search tasks with complex alphanumeric and spatial pattern materials intended to represent major classes of information processed by C<sup>2</sup> systems operators. Experiment 2 demonstrated reliable differences in the workload associated with CM and VM performance of a rule-based search task with alphanumeric materials. Similarly, the results of Experiment 3 showed that increased memory set size within a visual/memory search task with spatial pattern information was associated with increased subjective workload ratings under VM but not CM conditions. Thus, the results of both Experiments 2 and 3 are consistent with reductions in the workload associated with the automatic processing of information intended to represent C<sup>2</sup> system materials.

Although Experiments 2 and 3 demonstrated reduced levels of subjective workload in visual/memory search tasks, neither experiment directly addressed the issue of reductions in the processing resources associated with task performance or the levels of concurrent or dual task performance that would be associated with such reductions. Therefore, Experiment 12 was conducted to measure the workload imposed by CM and VM visual/memory search through application of a secondary task approach to workload assessment. This approach was based upon evaluation of the levels of dual task performance that could be achieved under the two mapping conditions.

Experiment 12  
Dual-Task Performance Under Automatic and Controlled Processing  
Conditions in a Visual/Memory Search Task with  
Spatial Pattern Information

Purpose

The purpose of this experiment was to investigate the workload levels associated with performance of visual/memory search tasks that required the processing of spatial pattern information under both CM and VM conditions.

A variety of techniques that have been used to assess the workload associated with operator performance (e.g., Eggemeier and Wilson, 1991; Hart and Wickens, 1990; O'Donnell and Eggemeier, 1986; Wilson and Eggemeier, 1991). Subjective assessment techniques, of the type used in Experiments 2 and 3, have been frequently employed to measure workload. Another major approach to workload measurement is secondary task methodology (e.g., Eggemeier and Wilson, 1991; O'Donnell and Eggemeier, 1986). This methodology requires the concurrent performance of a primary and secondary task. The primary task is the task of principal interest; a secondary task is added to gain an index of the workload associated with primary task performance. The basic rationale of secondary task methodology is that primary tasks that require high levels of resource/capacity expenditure will afford less additional capacity for secondary task performance, and will result in poorer levels of concurrent or dual-task performance than primary tasks that require lower levels of resource/capacity expenditure.

There are two major secondary task paradigms that can be applied to assess operator workload: (a) the subsidiary task paradigm, and (b) the loading task paradigm (e.g., Knowles, 1963; O'Donnell and Eggemeier, 1986). Both paradigms provide an assessment of primary task workload, but differ in the emphasis placed on primary or secondary task performance under dual-task

conditions. The subsidiary task paradigm emphasizes maintenance of primary task performance at single-task levels, with the assumption that the level of secondary task performance will provide an index of the amount of resource/capacity expenditure associated with the primary task.

The loading task paradigm emphasizes maintenance of secondary task performance at single-task levels under concurrent-task conditions. The secondary task in this paradigm imposes additional loading on the primary task, with the intent of simulating the processing load associated with other tasks or operator functions performed in an operational environment. Within this paradigm, decrements in primary task performance, incurred under dual-task conditions, represent the measure of primary task workload. The loading task paradigm assumes that tasks requiring a high level of capacity/resource expenditure will show larger decrements with the addition of the secondary task than will primary tasks that require lower levels of capacity expenditure. The loading task paradigm was chosen for application in this study because it simulates the demands of additional operator functions or tasks within the system environment and requires emphasis of secondary task performance under dual-task conditions.

$C^2$  systems operators are often required to perform concurrent functions or tasks. Thus, the resource expenditure or workload reductions that are typically associated with automatic processing could represent a major advantage to  $C^2$  systems operators. Consequently, it was considered important to investigate the workload associated with CM versus VM performance through application of secondary task methodology within a visual/memory search task that required processing of static spatial pattern information. The visual/memory search task was the same used in Experiment 3.

## Method

Subjects. The same 16 subjects who had previously participated in Experiment 3 also served as subjects in this experiment. They were paid \$3.75/hour for their participation. Subjects were awarded a bonus payment of \$1.25/hour for appearing on time for each scheduled experimental session.

Apparatus. The experiment was controlled with a Zenith Data Systems 248 computer which was programmed to present stimuli, control the timing of stimulus presentation, and collect subject responses. Subjects viewed spatial pattern stimuli on a Zenith ZCM-1490 high-resolution, thirteen-inch color monitor. Responses were made on the numeric keypad located in the lower right-hand corner of a standard expanded IBM-compatible keyboard. Auditory feedback concerning performance was presented to subjects through the speakers on the Zenith computers.

Procedure. Subjects performed two visual/memory search tasks under both single-task and dual-task conditions. One task was designated the primary task; the other was designated the secondary task. Both tasks were similar to a paradigm utilized by Strayer and Kramer (1990). The primary task was the same visual/memory search task used in Experiment 3. The secondary task was identical in procedure to the primary task, but required that different static spatial patterns be stored in memory and searched on test displays. The primary task was presented under either CM or VM conditions. The eight subjects trained on the primary task under CM conditions in Experiment 3 continued with that mapping in the present experiment under both single-task and dual-task conditions. The remaining eight subjects, trained under VM conditions on the primary task in Experiment 3, continued with that mapping in the present experiment during both single-task and dual-task performance. The secondary task was always performed by both primary task groups under VM conditions.

The single-task performance procedure was identical for both the primary and secondary tasks. On each set of ten trials, subjects were shown a memory set of either two or four spatial patterns on the CRT screen. These spatial patterns remained on the screen until either the subject pressed a designated key or 30 seconds elapsed. The memory set was replaced on the screen by the first of ten probe items. Each item consisted of two spatial patterns, one of which was a member of the memory set. The patterns in each probe were presented adjacent to one another, such that one occupied a position on the left, and the other on the right. Each probe set subtended a horizontal visual angle of approximately 6.9 degrees for a subject seated in the normal position with respect to the display. A probe remained on the screen for five seconds or until the subject responded. If five seconds elapsed without a subject response, the probe was removed from the screen and that trial was scored as an incorrect response. The inter-probe interval was 500 ms. There were an equal number of memory set size two and memory set size four trial blocks within each session. These blocks alternated with one another. Half the subjects completed a block of memory set size four trials followed by a block of memory set size two trials; the remaining subjects received the opposite order.

Subjects were instructed to rapidly determine which of the two test patterns was a member of the previously presented memory set. Subjects responded by indicating the position of the target pattern within the probe. The "four" key on the numeric keypad indicated the "left" pattern and the "five" key indicated the "right" pattern. A target was present within each probe set; its position within the probe was determined randomly on a trial-by-trial basis. Two dependent performance measures, reaction time and response accuracy, were collected. Subjects were encouraged to respond as rapidly as possible while maintaining a 90-percent accuracy level or higher within each session.

Auditory feedback was provided to subjects at the completion of each trial. An incorrect response was followed by a low pitched tone; a correct response was followed by a higher pitched tone.

Additional summary feedback presented at the conclusion of each ten-trial block provided correct response reaction time and accuracy performance levels from the block of trials. Subjects recorded this feedback on a response sheet to track changes in their performance as a function of training. Summary feedback was also provided to the subjects at the end of each session. This feedback, presented on the CRT, summarized mean correct response reaction time and percent correct responses for memory set size two and size four across the session.

The dual-task performance procedure was the same as that used under single-task conditions, with the following exceptions. Under dual-task conditions, trial block size was increased to 20 trials: ten primary task trials and ten secondary task trials. Test probes for the primary and secondary tasks alternated in the series of 20 trials. At the beginning of a block of dual-task trials, two memory sets were presented. The first of these was for the primary task, the second was for the secondary task. The presentation of probes followed the same sequence; that is, the first of the twenty probes within a trial block was associated with the primary task, while the second probe was associated with the secondary task. The remaining probes followed the same sequence of alternation. The same response keys used during single-task conditions were used for both primary and secondary task probes under dual-task conditions. At the conclusion of a block of twenty dual-task trials, subjects received accuracy and response time feedback for both tasks. Session feedback, similar to that provided under single-task trials, was also provided. This feedback was supplemented by experimenter feedback at the conclusion of each session. Experimenter feedback was used to

encourage subjects to maintain single-task baseline levels of secondary performance under dual-task conditions.

Subjects participated in the experiment for 5 days. The experiment was divided into two phases: (a) single-task training, and (b) dual-task performance.

The first two days of the experiment constituted the single-task training phase. This phase was devoted to initial training of the secondary task, and to training that alternated blocks of secondary task training and additional primary task practice. On each of these initial training days, subjects completed two half-hour training sessions which consisted of 32 ten-trial blocks on the secondary task. These training sessions were followed by two additional half-hour sessions in which blocks of single-task trials alternated between the primary and secondary tasks. During each session, there were 16 ten-trial blocks of single-task practice on the primary task, and 16 blocks of single-task practice on the secondary task. The purpose of the latter sessions was to provide subjects practice in performing the primary and secondary tasks on alternate blocks of trials. At the conclusion of the initial two days of training, subjects had received 1920 trials of training on the secondary task and 640 trials of additional training on the primary task. These 640 additional primary task trials, when coupled with the 8000 trials provided during Experiment 3, resulted in 8640 total primary task acquisition trials that preceded the dual-task phase of this experiment.

The final three days of the experiment constituted the dual-task phase, which was the principal interest in this investigation. During this phase, subjects performed blocks of both single- and dual-task trials on the primary and secondary tasks. Each session during the dual-task phase consisted of 24 blocks of trials: 16 single-task blocks and eight dual-task blocks.

Each dual-task block included twenty trials, and consisted of one of the four combinations of the different memory set conditions in the primary and secondary tasks. These combinations included: (a) Primary Task memory set size two performed concurrently with Secondary Task memory set size two (PT2/ST2), (b) Primary Task memory set size two performed concurrently with Secondary Task memory set size four (PT2/ST4), (c) Primary Task memory set size four performed concurrently with Secondary Task memory set size two (PT4/ST2), and (d) Primary Task memory set size four performed concurrently with Secondary Task memory set size four (PT4/ST4). Blocks 5 through 8 in each session were dual-task blocks, with each block representing one of the four combinations noted above. The order of presentation for each dual-task combination was counterbalanced across subjects through use of a Latin-square procedure. These blocks were preceded and followed by four blocks of single-task trials, each of which represented one of the memory set conditions (PT2, PT4, ST2, ST4) in either the primary or secondary task. Therefore, Blocks 1 through 4 and Blocks 9 through 12 represented single-task blocks in each session. Each of the single-task blocks consisted of ten trials. This sequencing of single-task and dual-task blocks was followed in the remaining 12 blocks of each session, such that Blocks 13 through 16 and Blocks 21 through 24 were single-task, and Blocks 17 through 20 were dual-task. Therefore, each session consisted of 160 dual-task trials and 160 single-task trials. Subjects completed four sessions each day, for a total of 1920 dual-task trials and 1920 single-task trials.

Priority instructions to subjects indicated that secondary task performance should be maintained at single-task baseline levels on dual-task trials. Therefore, the experiment employed the secondary loading task paradigm (e.g., Knowles, 1963; O'Donnell and Eggemeier, 1986) discussed above, in which decrements in primary task performance are of principal interest

in assessing the workload imposed by the primary task. As an aid in maintaining secondary task performance at single-task baselines, written feedback concerning reaction time and accuracy performance on the secondary task from the preceding session was provided to subjects.

Stimulus Materials. Each primary task spatial stimulus pattern, composed of six or seven asterisks, was intended to represent the type of pattern processed by some Air Force C<sup>2</sup> systems operators. There were an equal number of six- and seven-element patterns in the primary task stimulus set. For use during CM conditions, two different target/distractor sets were developed through a random selection procedure from the set of 12 patterns that made up the stimulus set. Each set for the CM condition included six target and six distractor patterns.

Secondary task stimuli (also static spatial patterns) consisted of three or five square elements. These patterns, less complex than those associated with the primary task, were chosen on the basis of pilot data to facilitate performance of the secondary task. Different numbers and shapes of pattern elements were used in the secondary and primary task patterns to aid subjects in discriminating those patterns associated with the respective tasks. Eight patterns were included in the secondary task stimulus set. Since the secondary task was always a VM task, targets and distractors were randomly chosen on a block-by-block basis from the total stimulus set.

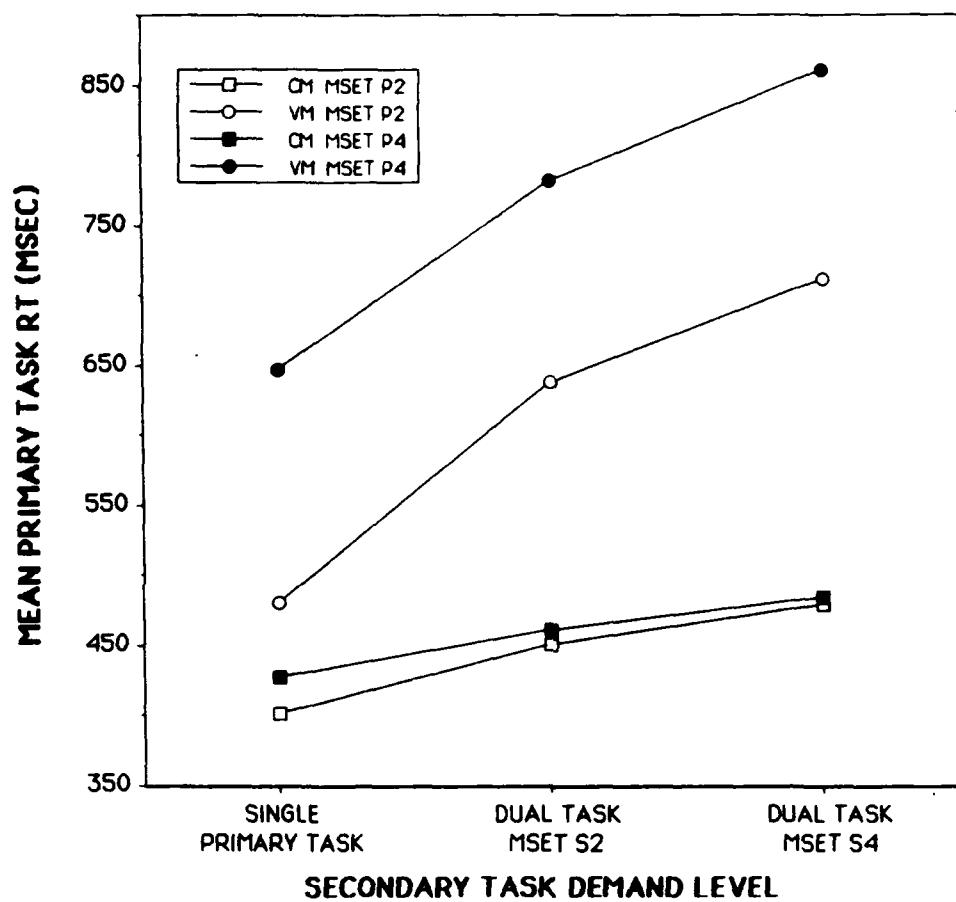
Design. Four independent variables were included in the dual-task design: (a) primary task target/distractor mapping, (b) memory set size of the primary task, (c) memory set size of the secondary task, and (d) sessions. Primary task target/distractor mapping (either CM or VM) represented a between-subjects variable. Eight subjects had been randomly assigned to the primary task CM group and eight to the primary task VM group during Experiment 3.

## Results

This results section is organized around several subsections that deal with primary and secondary task performance during the dual-task phase of the experiment. Primary task results are given first, followed by a report of the secondary task results.

Primary Task Reaction Time. Primary task mean reaction time as a function of CM/VM condition, primary task memory set size, and the level of concurrent secondary task demand is illustrated in Figure 12-1. Primary task performance is depicted under single-task conditions which did not involve concurrent performance of the secondary task, and under dual-task conditions which involved concurrent performance of the secondary task under memory set sizes of two and four patterns. The means are based on correct responses. As illustrated in the figure, CM performance was superior to VM performance under single-task conditions. This was expected and reflects the typical pattern of performance under CM and VM conditions anticipated as a result of the extensive training subjects had received. Also, as expected, CM performance was relatively unaffected by primary task memory load. Most importantly, from the standpoint of assessing primary task workload, CM performance was relatively unaffected by the addition of the secondary task and manipulations of secondary task memory load levels. VM performance, on the other hand, showed a more substantial decrement with the addition of the secondary task than did CM performance, and was also more markedly affected by the increase in secondary task demand levels.

A  $2 \times 2 \times 3 \times 12$  ANOVA was performed on the primary task reaction time data to analyze the effects of mapping condition (CM versus VM), primary task memory set size (2 or 4), secondary task demand level (0, 2, or 4), and sessions (1-12). Mapping condition was a between-subjects variable in this analysis, while



**Figure 12-1.** Primary Task Mean Reaction Time as a Function of Mapping Condition, Primary Task Memory Set Size, and Secondary Task Demand.

primary task memory set size, secondary task demand level, and training session were within-subjects variables. It should be noted that the 0 level of secondary task demand indicates the absence of the secondary task and constitutes the primary-task single-task control in this analysis. Secondary task demand levels of two and four refer to the sizes of the secondary task memory set and represent an index of the demand imposed by the secondary task under dual-task conditions.

The ANOVA indicated that the main effects of mapping condition ( $F(1,14) = 63.19$ ,  $p < .001$ ,  $MS_e = 252194.88$ ), primary task memory set size ( $F(1,14) = 154.45$ ,  $p < .001$ ,  $MS_e = 13058.28$ ), secondary task demand level ( $F(2,28) = 88.98$ ,  $p < .001$ ,  $MS_e = 23445.83$ ), and training sessions ( $F(11,154) = 1.96$ ,  $p < .05$ ,  $MS_e = 8017.05$ ) were significant. The interactions of CM/VM and primary task memory set ( $F(1,14) = 106.82$ ,  $p < .001$ ), CM/VM and secondary task demand level ( $F(2,28) = 25.76$ ,  $p < .001$ ), primary task memory set and sessions ( $F(11,154) = 2.19$ ,  $p < .05$ ,  $MS_e = 2951.91$ ), and secondary task demand level and sessions ( $F(22,308) = 2.03$ ,  $p < .01$ ,  $MS_e = 4419.50$ ) were also significant. Finally, the three-way interaction of CM/VM, primary task memory set size, and sessions ( $F(11,154) = 2.36$ ,  $p < .05$ ) was reliable. None of the other interactions proved to be significant.

The result of principal interest to the assessment of the workload associated with primary task performance is the significant interaction of mapping condition with secondary task demand level. Compared to VM performance, CM performance was relatively unaffected by the addition or manipulation of the secondary task. This was noted above in conjunction with the discussion of Figure 12-1. To investigate the CM/VM and secondary task demand level interaction, tests of secondary task demand level effects were performed within the CM and VM conditions. These analyses demonstrated that the effect of secondary task demand level was significant within both

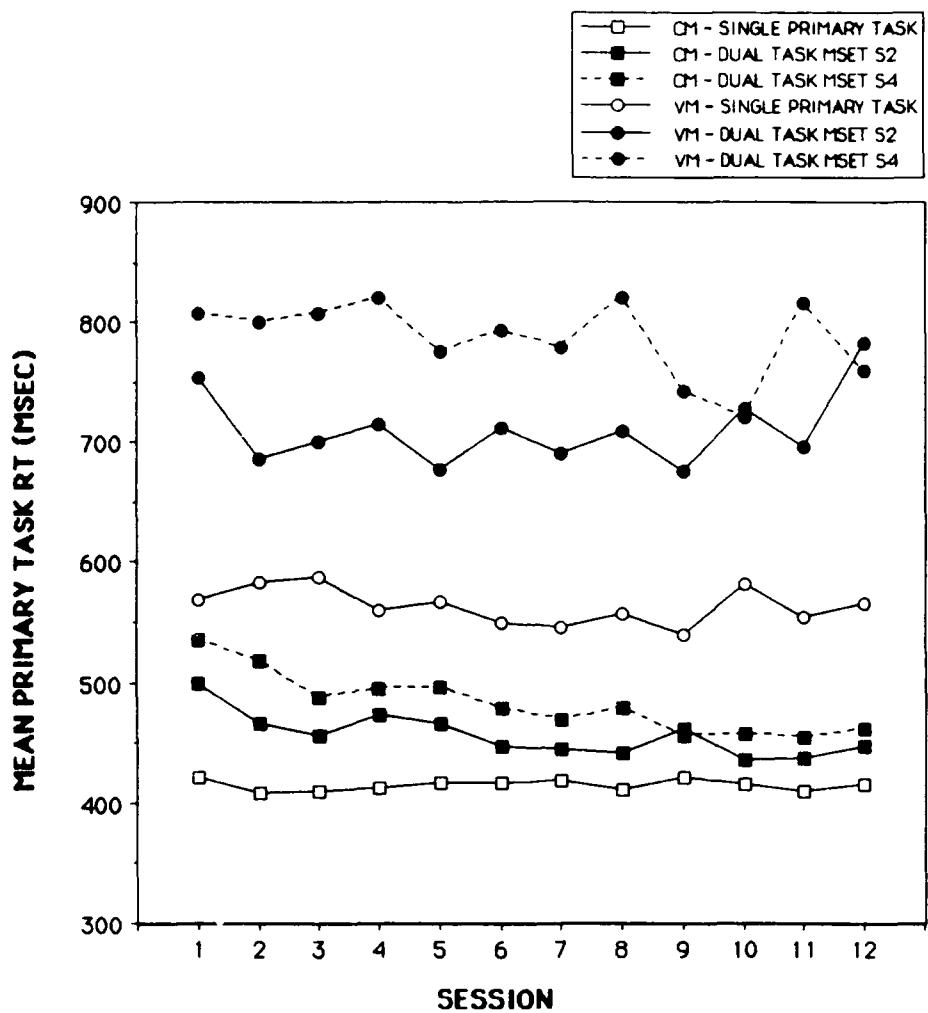
the CM ( $F(2,28) = 9.52$ ,  $p < .005$ ,  $MS_e = 23445.83$ ) and VM ( $F(2,28) = 105.22$ ,  $p < .001$ ) conditions.

Contrasts, performed to further investigate the secondary task demand level effects, indicated that within the CM condition, the single-task baseline was significantly different from both the memory set size two dual-task condition ( $F(1,14) = 8.50$ ,  $p < .05$ ,  $MS_e = 19291.79$ ) and the memory set size four dual-task condition ( $F(1,14) = 10.80$ ,  $p < .05$ ,  $MS_e = 40653.42$ ). The effect of secondary task demand levels within dual-task performance were also reliable; that is, the memory set size two dual-task condition differed significantly from the memory set size four dual-task condition ( $F(1,14) = 6.93$ ,  $p < .05$ ,  $MS_e = 10392.29$ ). Comparable analyses within the VM condition also demonstrated that the single-task baseline differed reliably from both the memory set size two dual-task condition ( $F(1,14) = 106.33$ ,  $p < .001$ ) and the memory set size four dual-task condition ( $F(1,14) = 117.60$ ,  $p < .001$ ). In addition, the memory set size two dual-task condition differed significantly from the memory set size four dual-task condition ( $F(1,14) = 54.75$ ,  $p < .001$ ). As is clear from the magnitude of the  $F$  ratios, the size of the secondary task demand level effect was considerably greater in each instance under the VM versus the CM condition. Eta squared analyses confirmed this trend and showed larger effects in VM versus CM conditions in the comparisons of: (a) single-task baseline with memory set size two condition (.884 versus .378), (b) single-task baseline with memory set size four condition (.893 versus .436), and (c) memory set size two condition with memory set size four condition (.796 versus .313). Although there were significant decrements in CM performance with both the introduction of the secondary task and with increases in its demand level, these decrements did not approach the magnitude of comparable effects present within the VM condition.

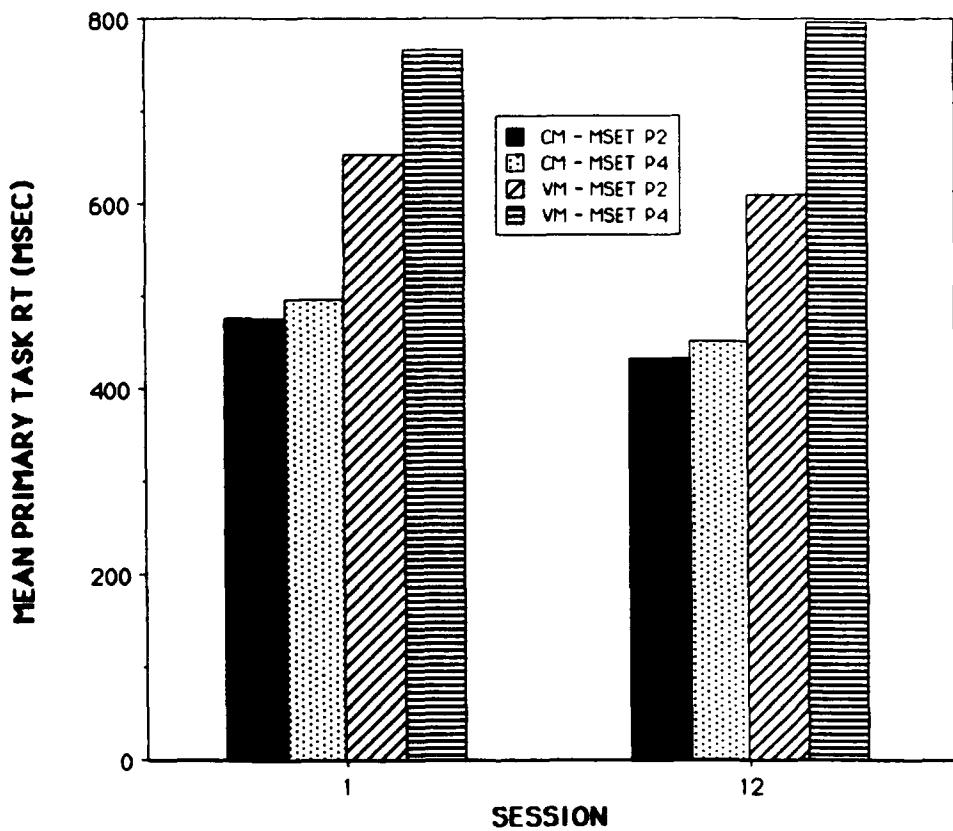
The overall ANOVA also demonstrated a reliable interaction of secondary task demand level with sessions. Figure 12-2 depicts mean primary task reaction time as a function of mapping condition, secondary task demand level, and sessions. As seen in the figure, there is some attenuation of secondary task demand level effects on primary task performance as sessions progress. This is particularly noticeable in the effect of dual-task demand levels on performance.

To investigate the significant interaction, tests of secondary task demand level effects were performed within the first and last dual-task sessions. These analyses showed that the effect of secondary task demand level was significant within both Session 1 ( $F(2,28) = 69.12, p < .001, MS_e = 3904.66$ ) and Session 12 ( $F(2,28) = 12.01, p < .001, MS_e = 13177.59$ ). Eta squared analyses indicated the size of secondary task demand level effect was greater during Session 1 (.832) than during Session 12 (.462); this is consistent with the trend for attenuation of secondary task demand effects noted in Figure 12-2.

Figure 12-3 depicts primary task mean reaction time as a function of mapping condition and primary task memory set size in Sessions 1 and 12. The three-way interaction of mapping condition, primary task memory set size, and sessions was reliable in the overall analysis. To further investigate this interaction, tests of mapping condition and memory set size effects were conducted within Sessions 1 and 12. These analyses showed that the main effects of mapping condition ( $F(1,14) = 43.05, p < .001, MS_e = 28059.37$ ) and primary task memory set size ( $F(1,14) = 43.71, p < .001, MS_e = 2483.75$ ) were significant within Session 1, as was the interaction of mapping condition and memory set size ( $F(1,14) = 21.24, p < .001$ ). Analyses of the Session 12 data demonstrated that the main effects of mapping condition ( $F(1,14) = 49.83, p < .001, MS_e = 32809.97$ ) and primary task memory set size



**Figure 12-2.** Primary Task Mean Reaction Time as a Function of Mapping Condition, Secondary Task Demand, and Session.

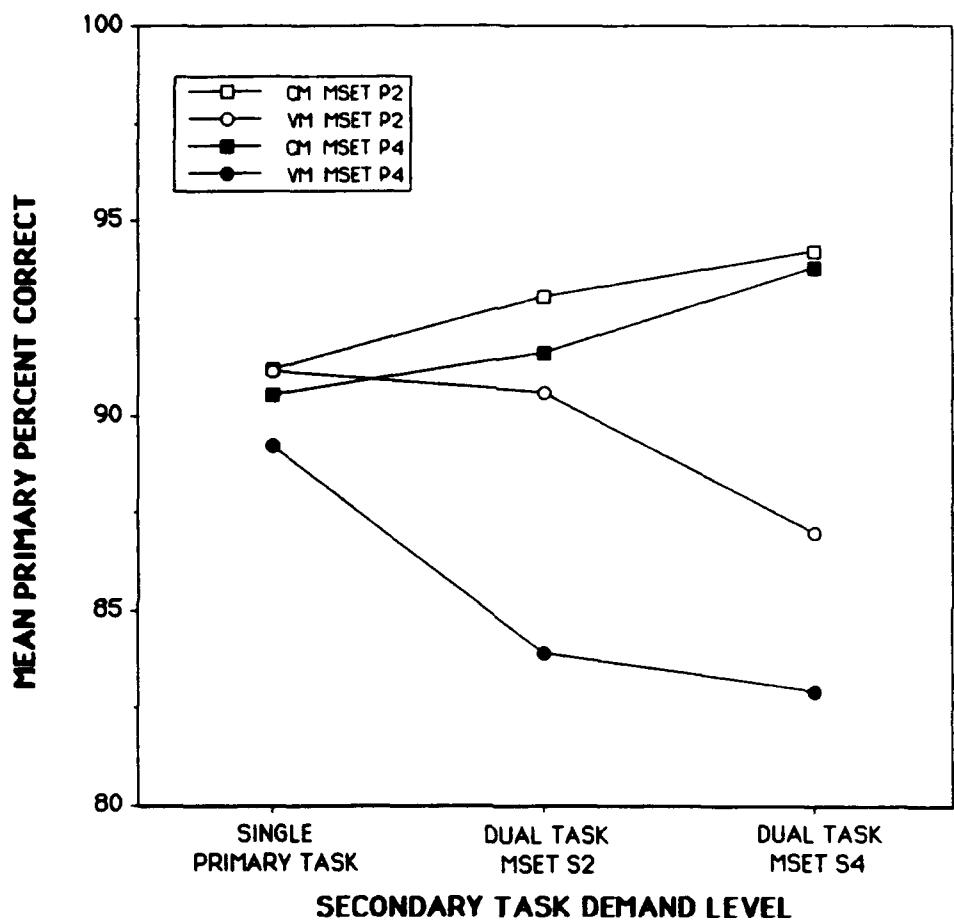


**Figure 12-3.** Primary Task Mean Reaction Time as a Function of Mapping Condition, Primary Task Memory Set Size, and Session.

( $F(1,14) = 59.97$ ,  $p < .001$ ,  $MS_e = 4240.11$ ) were significant, as was the mapping condition and memory set size interaction ( $F(1,14) = 41.05$ ,  $p < .001$ ). To follow up the significant mapping condition and memory set interaction, tests of the memory set effect were performed within the CM and VM conditions at Session 1. These analyses indicated that the memory set size effect was significant within the VM condition ( $F(1,14) = 62.95$ ,  $p < .001$ ,  $MS_e = 2483.75$ ), but not the CM condition ( $F(1,14) = 2.01$ ,  $p > .05$ ).

Comparable analyses were performed on the Session 12 data. These analyses showed that the memory set size effect was significant within the VM condition ( $F(1,14) = 100.12$ ,  $p < .001$ ,  $MS_e = 4240.11$ ) but not the CM condition ( $F(1,14) = 0.89$ ,  $p > .05$ ). Eta squared analyses indicated that the size of the memory set effect in the CM condition showed a slight decline between Sessions 1 (.125) and 12 (.060). The size of the memory set effect in the VM condition demonstrated the opposite pattern and showed a slight increase from Session 1 (.818) to Session 12 (.877). These differences in the pattern of the effect are reflected in the significant interaction.

Primary Task Accuracy. Primary task mean percent correct as a function of CM/VM condition, primary task memory set size, and the level of concurrent secondary task demand is depicted in Figure 12-4. As with the mean reaction time data, primary task performance is shown under single-task conditions which did not involve concurrent performance of the secondary task, and under dual-task conditions which involved concurrent performance of the secondary task under memory set sizes of two and four patterns. As indicated by the figure, single-task performance was very similar in all conditions and closely approximated the stipulated 90-percent criterion. The introduction of the secondary task was accompanied by slight accuracy increases within the CM condition, and by some accuracy decreases within the VM condition. The VM



**Figure 12-4.** Primary Task Mean Percent Correct as a Function of Mapping Condition, Primary Task Memory Set Size, and Secondary Task Demand.

decrements were most pronounced at the high level of secondary task demand.

A  $2 \times 2 \times 3 \times 12$  ANOVA was performed on the primary task percent correct data to analyze the effects of mapping condition (CM versus VM), primary task memory set size (2 or 4), secondary task demand level (0, 2, or 4), and sessions (1-12). As in the reaction time analysis, mapping condition was a between-subjects variable, while primary task memory set size, secondary task demand level, and training sessions were within-subjects variables. The 0 level of secondary task demand indicates the absence of the secondary task and constitutes the primary-task single-task control in this analysis. Secondary task demand levels of two and four refer to the sizes of the secondary task memory set and represent an index of the demand imposed by the secondary task under dual-task conditions.

The ANOVA demonstrated that the main effects of mapping condition ( $F(1,14) = 7.90$ ,  $p < .001$ ,  $MS_e = 892.59$ ) and primary task memory set size ( $F(1,14) = 44.06$ ,  $p < .001$ ,  $MS_e = 41.71$ ) were significant. However, the main effects of secondary task demand level ( $F(2,28) = 1.25$ ,  $p > .05$ ,  $MS_e = 90.21$ ) and training sessions ( $F(11,154) = 1.24$ ,  $p > .05$ ,  $MS_e = 59.18$ ) were not significant. The interactions of CM/VM and primary task memory set ( $F(1,14) = 19.58$ ,  $p < .001$ ), CM/VM and secondary demand level ( $F(2,28) = 18.73$ ,  $p < .001$ ), CM/VM and sessions ( $F(11,154) = 2.09$ ,  $p < .001$ ), and primary task memory set size and secondary task demand level ( $F(2,28) = 4.57$ ,  $p < .005$ ,  $MS_e = 42.05$ ) were also significant. In addition, the three-way interaction of CM/VM, sessions, and primary task memory set size ( $F(11,154) = 2.55$ ,  $p < .01$ ,  $MS_e = 30.67$ ), and the four-way interaction of CM/VM, sessions, primary task memory set size, and secondary task demand level ( $F(22,308) = 1.82$ ,  $p < .05$ ,  $MS_e = 36.23$ ) were reliable. None of the other interactions were significant.

Figure 12-5 shows primary task mean percent correct as a function of mapping condition, primary task memory set size, and secondary task demand level in Sessions 1 and 12. As depicted in the figure, CM performance is consistently superior to VM performance within Session 1, and the pattern of the effect of secondary task demand on performance differs as well. Within the CM condition, there is a tendency to improve accuracy with the introduction of the secondary task, while within the VM condition, performance shows some tendency to deteriorate. Both mapping conditions show little effect of the increase in secondary task memory set size from two to four patterns. The Session 12 data continue to show the superiority of the CM condition over the VM condition. In addition, CM performance is relatively unaffected by either the size of the primary task memory set or the levels of secondary task demand. VM performance, on the other hand, shows a greater tendency to be affected by primary task memory set size and secondary task demand levels than was the case in Session 1. The latter effect is particularly noticeable as secondary task memory set size was increased from two to four patterns under dual-task conditions.

To investigate the reliable four-way interaction, a  $2 \times 2 \times 3$  ANOVA, which examined the effects of CM/VM, primary task memory set size, and secondary task demand level, was performed on the data from Sessions 1 and 12. The Session 1 analysis showed that the main effect of mapping condition ( $F(1,14) = 7.64$ ,  $p < .05$ ,  $MS_e = 81.81$ ) was significant, but the main effects of primary task memory set size ( $F(1,14) = 4.30$ ,  $p > .05$ ,  $MS_e = 17.52$ ) and secondary task demand level ( $F(2,28) = 0.16$ ,  $p > .05$ ,  $MS_e = 59.93$ ) were not. None of the interactions proved to be significant. The Session 12 data analysis indicated that the main effects of mapping condition ( $F(1,14) = 9.39$ ,  $p < .01$ ,  $MS_e = 94.89$ ) and primary task memory set size ( $F(1,14) = 13.28$ ,  $p < .005$ ,  $MS_e = 17.07$ ) were significant, but the main effect of secondary task demand level

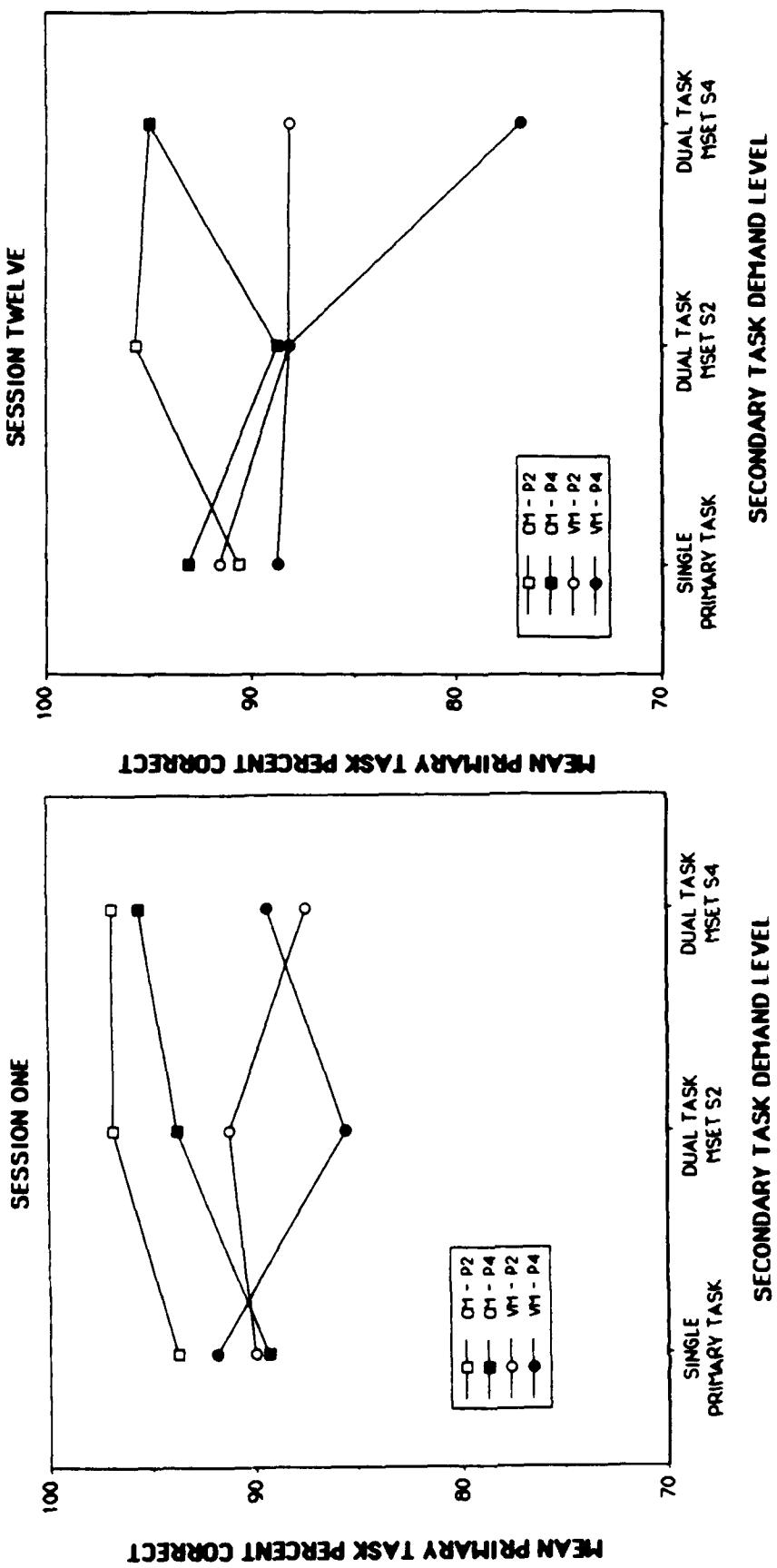


Figure 12-5. Primary Task Mean Percent Correct as a Function of Mapping Condition, Primary Task Memory Set Size, Secondary Task Demand, and Session.

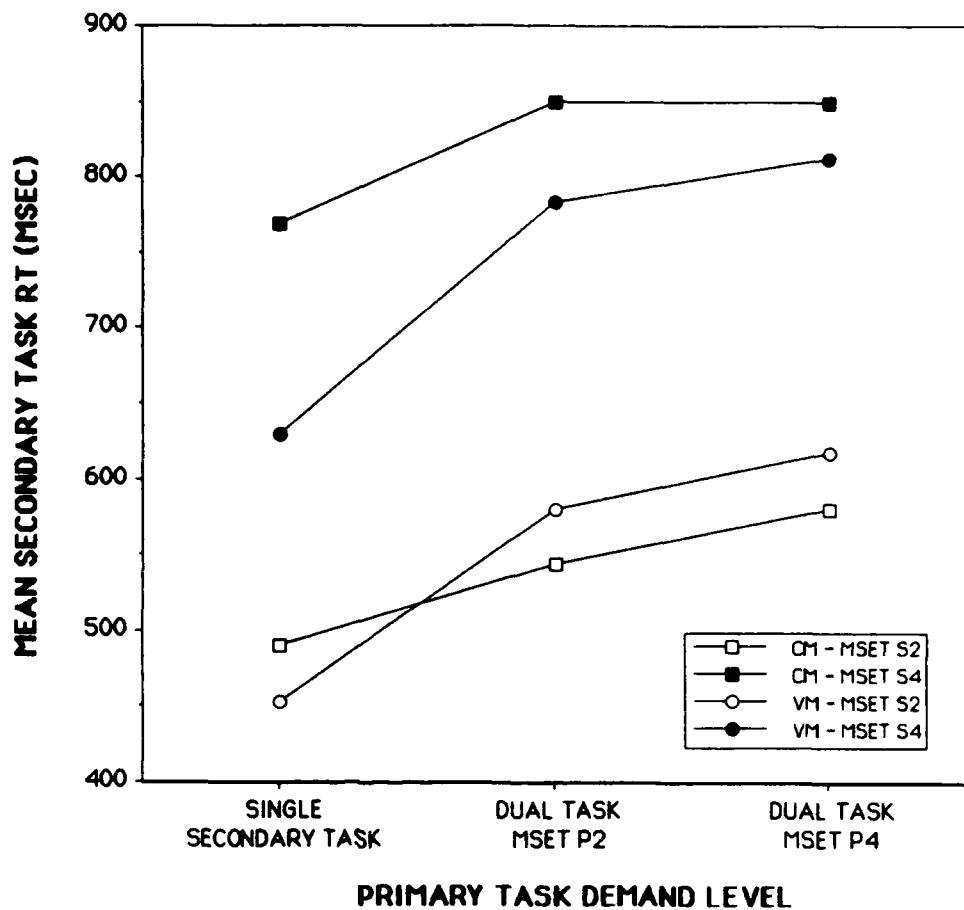
( $F(2,28) = 0.77$ ,  $p > .05$ ,  $MS_e = 54.60$ ) was not. The CM/VM and secondary task demand level interaction ( $F(2,28) = 4.71$ ,  $p < .05$ ) was significant, as was the interaction of CM/VM, secondary task demand level, and primary task memory set size ( $F(2,28) = 4.05$ ,  $p < .05$ ,  $MS_e = 42.18$ ).

The reliable interaction of CM/VM, secondary task demand level, and primary task memory set size in Session 12 was followed by tests of the effects of secondary task demand level and primary task memory set size within the CM and VM conditions. These analyses indicated that within the CM condition, neither the main effect of primary task memory set size ( $F(1,14) = 1.50$ ,  $p > .05$ ,  $MS_e = 17.07$ ) nor the effect of secondary task demand level ( $F(2,28) = 0.87$ ,  $p > .05$ ,  $MS_e = 54.60$ ) were significant. Also, the interaction of the two variables proved to be nonsignificant ( $F(2,28) = 2.24$ ,  $p > .05$ ,  $MS_e = 42.18$ ). Within the VM condition, both the main effects of primary task memory set size ( $F(1,14) = 15.45$ ,  $p < .005$ ) and secondary task demand level ( $F(2,28) = 4.61$ ,  $p < .05$ ) were significant. The  $F$  value for the interaction of primary task memory set size and secondary task demand level approached but did not achieve the level required for significance ( $F(2,28) = 3.25$ ,  $p > .05$ ).

The primary task percent correct analyses demonstrate the consistent superiority of the CM versus the VM condition. In this respect, the analyses are consistent with the results of the primary task reaction time analyses. The data indicate that within the VM condition, Session 12 accuracy was affected by both primary task memory set size and secondary task demand levels. The latter effect was primarily observed as secondary task memory set size increased from two to four patterns. Because no such effects were observed in Session 1, the Session 12 data suggest that subjects in the VM condition may have adopted a speed/accuracy tradeoff strategy in the latter session. Such a strategy would account for some of the attenuation of secondary

task memory set size effects noted in the primary task reaction time analysis of Session 12.

Secondary Task Reaction Time. Secondary task mean reaction time as a function of primary task mapping condition, secondary task memory set size, and the level of concurrent primary task demand is illustrated in Figure 12-6. Secondary task performance is depicted under single-task conditions which did not involve concurrent performance of the primary task, and under dual-task conditions which involved concurrent performance of the primary task under memory set sizes of two and four patterns. The means depicted in the figure are based on correct responses. It is important to reiterate that the CM and VM designators refer only to the primary task mapping condition and the secondary task was performed under VM conditions by both primary task groups. Therefore, equivalent secondary task performance under single-task conditions was expected for the CM and VM groups. Instructions to subjects indicated that secondary task performance under dual-task conditions should be maintained at single-task baseline levels; therefore, no differences between mapping conditions were expected under dual-task conditions. As illustrated in the figure, the performance of the CM and VM groups approached equivalence under the memory set size two condition. However, the reaction times of the CM group tended to be higher than those of the VM group under the memory set size four condition. Both the CM and VM groups showed some decrement in secondary performance with the introduction of the primary task under dual-task conditions, despite the instructions to maintain secondary task performance at single-task baseline levels. As depicted in the figure, there is some tendency for the VM group to show larger decrements than the CM group with both the introduction of the primary task and with the increase in primary task demand from two to four memory set items. Finally, both mapping conditions demonstrated the expected effect of secondary task memory set size in that response latency was



**Figure 12-6.** Secondary Task Mean Reaction Time as a Function of Mapping Condition, Secondary Task Memory Set Size, and Primary Task Demand.

longer under the memory set size four condition than the memory set size two condition.

A  $2 \times 2 \times 3 \times 12$  ANOVA was performed on the secondary task reaction time data to analyze the effects of primary task mapping condition (CM versus VM), secondary task memory set size (2 or 4), primary task demand level (0, 2, or 4), and sessions (1-12). Mapping condition was a between-subjects variable in this analysis, while primary task memory set size, secondary task demand level, and training session were within-subjects variables. The 0 level of primary task demand indicates the absence of the primary task and represents the secondary-task single-task control in this analysis. Primary task demand levels of two and four refer to the sizes of the primary task memory set and serve as an index of the demand imposed by the primary task under dual-task conditions.

The ANOVA indicated that the main effects of primary task demand level ( $F(2,28) = 63.61$ ,  $p < .001$ ,  $MS_e = 28341.86$ ) and secondary memory set size ( $F(1,14) = 88.38$ ,  $p < .001$ ,  $MS_e = 1844882.53$ ) were significant, but the effects of primary task mapping condition ( $F(1,14) = 0.35$ ,  $p > .05$ ,  $MS_e = 944685.53$ ) and training sessions ( $F(11,154) = 1.84$ ,  $p > .05$ ,  $MS_e = 23089.57$ ) were not. The interaction of CM/VM and primary task demand level ( $F(2,28) = 7.56$ ,  $p < .005$ ) was also significant. No other interactions proved to be reliable. The main effect of secondary task memory set size was expected and reflects the trend noted above for higher reaction times under the memory set size four condition than the memory set size two condition.

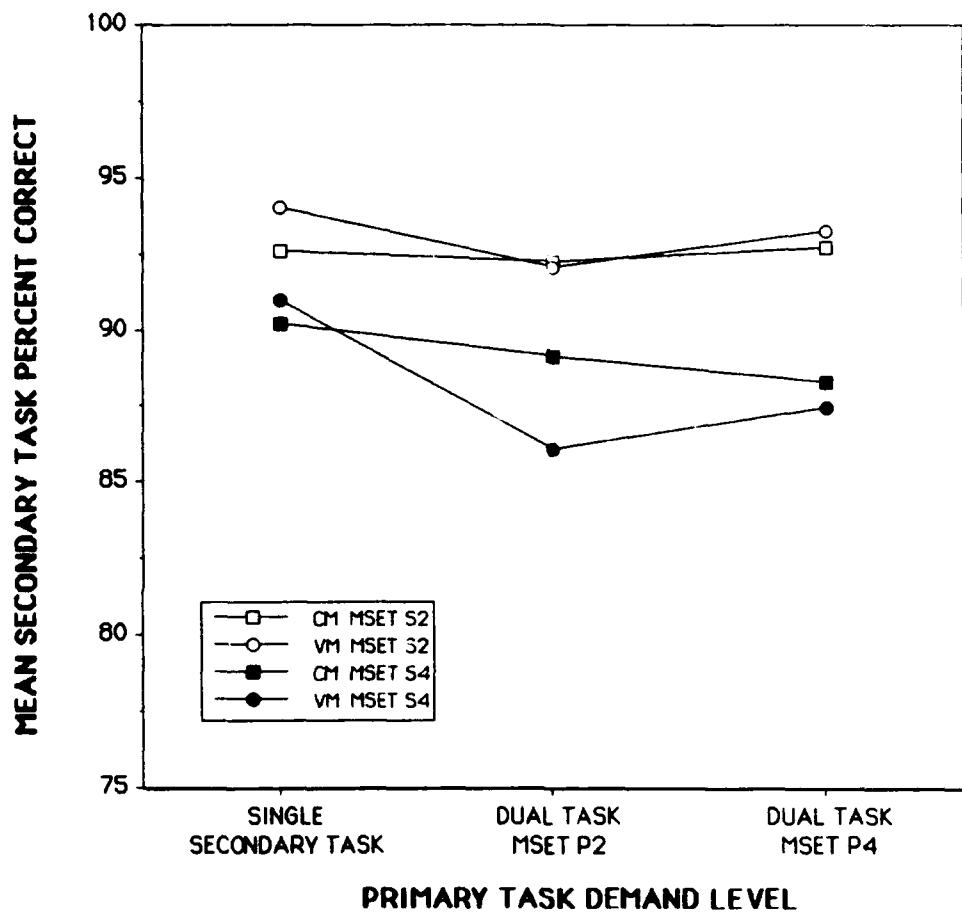
To investigate the significant CM/VM and primary task demand level interaction, tests of the primary task demand level effect were performed within the CM and VM conditions. These analyses indicated that the effect of primary task demand level was reliable within both the CM ( $F(2,28) = 13.67$ ,  $p < .001$ ,

$MS_e = 28341.86$ ) and VM ( $F(2,28) = 57.50, p < .001$ ) conditions. Eta squared analyses showed that the size of the primary task demand level effect was greater in the VM (.804) condition than in the CM (.494) condition. Contrasts showed that the decrement in performance between the single-task baseline and the dual-task memory set size two condition was reliable in both the CM ( $F(1,14) = 16.58, p < .001, MS_e = 26024.31$ ) and VM ( $F(1,14) = 72.78, p < .001$ ) conditions. Once again, Eta squared analyses demonstrated that the size of the effect was larger in the VM (.838) than the CM (.542) condition. The performance decrement between the single-task baseline and the dual-task memory set size four condition was also significant in both the CM ( $F(1,14) = 15.83, p < .001, MS_e = 44106.87$ ) and VM ( $F(1,14) = 65.53, p < .001$ ) conditions. Eta squared analyses indicated that, once again, the effect size was greater in the VM (.823) than the CM (.530) condition. Finally, the performance decrement under dual-task conditions which resulted from the increase in primary task memory set size from two to four patterns, was significant within the VM ( $F(1,14) = 7.04, p < .05, MS_e = 14894.40$ ), but not the CM ( $F(1,14) = 2.15, p > .05$ ) condition.

The results of the reaction time analysis indicate that, although decrements in secondary task performance occurred between the single-task baseline and dual-task conditions in both the CM and VM groups, the magnitude of the effect within the VM group was greater in both instances than in the CM group. Also, while the VM group demonstrated a significant decrement within dual-task performance as a function of the increase in the demand level of the primary task, the CM group showed no such decrement. Thus, these results are consistent with the primary task reaction time analyses and indicate that the performance of the CM group under dual-task timesharing conditions was superior to that of the VM group.

Secondary Task Accuracy. Secondary task mean percent correct as a function of primary task mapping condition, secondary task memory set size, and level of concurrent primary task demand is illustrated in Figure 12-7. Secondary task performance is depicted under single-task conditions which did not involve concurrent performance of the primary task, and under dual-task conditions which involved concurrent performance of the primary task under memory set sizes of two and four patterns. Once again, the CM and VM designators refer only to the primary task mapping condition. As with the reaction time data, equivalent secondary task performance was expected for the CM and VM groups under single- and dual-task conditions. As shown in the figure, the performance of the CM and VM groups was very similar under single-task conditions. The introduction of the primary task resulted in a tendency for some performance decrement under the secondary task memory set size four condition. However, this trend was somewhat more marked in the VM versus the CM group. There was also an overall trend for response accuracy to be lower under the secondary task memory set size four condition than under the memory set size two condition.

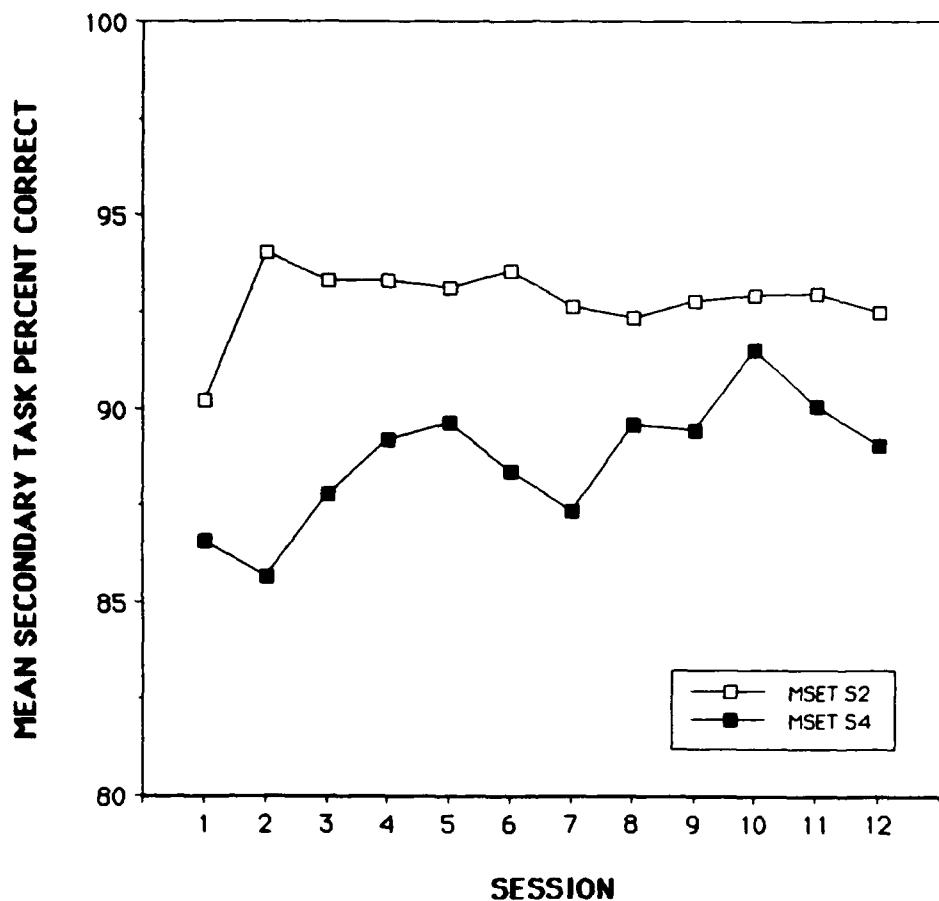
A  $2 \times 2 \times 3 \times 12$  ANOVA was performed on the secondary task mean percent correct data to analyze the effects of primary task mapping condition (CM versus VM), secondary task memory set size (2 or 4), primary task demand level (0, 2, or 4), and sessions (1-12). Mapping condition was a between-subjects variable; primary task memory set size, secondary task demand level, and training session were within-subjects variables. Once again, the 0 level of primary task demand indicates the absence of the primary task and represents the secondary-task single-task control in this analysis. Primary task demand levels of two and four again refer to the sizes of the primary task memory set and provide an index of the demand imposed by the primary task under dual-task conditions.



**Figure 12-7.** Secondary Task Mean Percent Correct as a Function of Mapping Condition, Secondary Task Memory Set Size, and Primary Task Demand.

The ANOVA demonstrated that the main effects of primary task demand level ( $F(2,28) = 7.92$ ,  $p < .005$ ,  $MS_e = 56.00$ ) and secondary memory set size ( $F(1,14) = 33.98$ ,  $p < .001$ ,  $MS_e = 144.09$ ) were significant. The main effects of primary task mapping condition ( $F(1,14) = 0.03$ ,  $p > .05$ ,  $MS_e = 475.07$ ) and sessions ( $F(11,154) = 1.82$ ,  $p > .05$ ,  $MS_e = 50.68$ ) were not reliable. The interaction of secondary task memory set size and sessions ( $F(11,154) = 2.38$ ,  $p < .01$ ,  $MS_e = 32.05$ ) was significant. There were no other significant interactions. The main effect of primary task demand level represents the tendency noted above for decreased accuracy in both mapping groups under dual-task conditions compared to the single-task baseline. Likewise, the main effect of secondary task memory set size reflects the previously noted trend for performance decrements under the memory set size four condition relative to the size two condition.

Figure 12-8 shows secondary task mean percent correct as a function of secondary task memory set size and sessions. As depicted in the figure, performance tended to increase, within both memory set sizes across sessions. However, the trend is somewhat more marked in the memory set size four condition relative to the size two condition. This trend resulted in a reduction of the performance difference between the two memory set sizes at the conclusion of training. To investigate the significant interaction of secondary memory set size and sessions, tests of the memory set effect were performed within Sessions 1 and 12. These analyses indicated that the effect of memory set was significant within both Session 1 ( $F(1,14) = 6.75$ ,  $p < .05$ ,  $MS_e = 47.23$ ) and Session 12 ( $F(1,14) = 16.75$ ,  $p < .005$ ,  $MS_e = 16.93$ ). Therefore, although the absolute magnitude of the differences between set sizes was somewhat reduced during later sessions, the memory set size effect continued to be significant at Session 12.



**Figure 12-8.** Secondary Task Mean Percent Correct as a Function of Secondary Task Memory Set Size and Session.

The results of the secondary task accuracy analysis indicate that there were no reliable differences associated with the primary task mapping condition. Thus, the results provide no basis to infer the presence of a speed/accuracy tradeoff that could affect the interpretation of the mapping condition differences noted in the secondary task reaction time analyses. There were decrements in secondary task performance under both mapping conditions and, as expected, secondary task memory set size also affected performance accuracy under both mapping conditions.

### Discussion

The results of the present experiment indicate that the workload associated with a CM version of a spatial pattern visual/memory search task was lower than that associated with a VM version of the same task. The CM group showed a smaller decrement than the VM group in primary task reaction time and errors with both the introduction of the secondary loading task and manipulations of secondary task demand under dual-task conditions. Likewise, the CM group demonstrated a smaller decrement in secondary task reaction time than the VM group under conditions that required concurrent primary task performance. The CM group also failed to show any decrement with increases in primary task demand under dual-task conditions. Both mapping conditions showed statistically equivalent secondary task accuracy decrements under dual-task conditions.

A potentially important advantage of automatic processing of C<sup>2</sup> operator task components is the reduction in workload associated with automatized functions, with a resulting increase in the capability of the operator to perform concurrent functions. The present results confirm the workload or resource expenditure reductions that can be associated with automatic processing of the type of spatial pattern information incorporated in some C<sup>2</sup> systems. Thus, the results demonstrate

the viability of an automatic processing approach under the conditions represented in the current experiment.

The present data also are consistent with previous results with alphanumeric, semantic, and other forms of spatial information (e.g., Fisk and Lloyd, 1988; Fisk and Schneider, 1983; Schneider and Fisk, 1982, 1984; Strayer and Kramer, 1990; Venturino, 1991) that have demonstrated high levels of dual-task performance under CM conditions. Future research of importance to eventual applications of automatic processing to C<sup>2</sup> operator training should investigate the workload associated with processing dynamic spatial pattern information and with performance of rule-based alphanumeric visual/memory search tasks of the type investigated in Experiment 2.

An additional issue for future research in this area concerns the workload associated with task performance over the types of retention intervals investigated in the previous series of experiments. Experiment 11 showed increases in subjective workload within a rule-based alphanumeric search task over a 26-day interval. An important issue not addressed by Experiment 11 concerns the implication of any such workload increases with respect to dual task performance of the type evaluated here. It is possible that workload increases would compromise dual-task efficiency under conditions in which primary task performance remained relatively stable. Thus, efficiency of dual-task performance constitutes an additional criterion that should be applied in future evaluations of retention interval effects on CM and VM performance.

## VI. GENERAL SUMMARY AND CONCLUSIONS

The experiments described in this report provide information concerning the acquisition, transfer, and retention of automatic processing with spatial pattern and complex alphanumeric materials intended to represent major classes of information found within C<sup>2</sup> systems. A number of the present experiments also addressed the issue of workload associated with performance of search tasks that require the processing of that information.

The results of the first series of experiments that dealt with the acquisition of automatic processing indicate that such processing can be developed with both spatial pattern and complex alphanumeric information in search tasks representative of operator component functions within C<sup>2</sup> systems. Experiments 1 and 2 demonstrated performance differences between CM and VM conditions that were consistent with some level of automatic processing development within the CM condition in memory search and visual/memory search tasks, respectively. Both experiments dealt with the processing of complex alphanumeric information that required the conjunction of alphabetic sequences with a range of numerical values.

Experiment 1 incorporated several levels of consistency. Performance levels at the conclusion of training paralleled the degree of consistency present in the task. Operator functions within C<sup>2</sup> systems can also be expected to incorporate different levels of consistency. The present results suggest that, with training, operator performance should also reflect the consistencies present within complex tasks. Experiment 2, which extended the results of Experiment 1 to a visual/memory search paradigm, indicated that automatic processing can also be established with this more complex type of search function. Visual/memory search represents an important component of some C<sup>2</sup> operator functions; the present results indicate that automatic

processing can be developed with complex alphanumeric materials in this type of search paradigm.

Experiments 3 and 4 addressed the issue of automatic processing development with spatial pattern information in visual/memory search tasks. Experiment 3 extended the results of earlier memory search work to somewhat more complex static spatial pattern information than had been used in the previous research. CM performance was superior to VM performance, and the results were consistent with some degree of automatic processing development in the CM condition. Experiment 4 investigated the effect of whole-task versus part-task training on automatic processing development. This experiment also examined the effect of variations in both display load and memory load on performance under CM and VM conditions. The part-task training paradigm employed had no impact on performance levels within the CM condition and does not appear to represent a viable approach to facilitating automatic processing development with the type of spatial pattern information used in the experiment. The results indicated that, with training, CM memory load effects were more markedly attenuated than were CM display load effects, relative to the VM baseline. This result, of considerable potential importance to eventual applications to C<sup>2</sup> training systems, represents an area for continued research.

The results of the second series of experiments, which addressed the issue of transfer, demonstrated the transfer of automatic processing under some conditions. However, the results also indicated that there can be important limits on transfer with spatial pattern information. Experiments 5 and 6, extensions of Experiments 1 and 2, demonstrated some evidence of automatic processing transfer to untrained exemplars of trained alphanumeric rules. The results of Experiments 5 and 6 indicate that training programs, designed to establish automatic processing with rule-based tasks of the present type, can be structured to make use of transfer to untrained exemplars. In

addition to their practical significance, the results suggest that the locus of the automatic processing developed through training was at least partially based at the rule level rather than the exemplar level.

Experiment 7 investigated the effect of pattern rotation on performance under CM and VM conditions, using the static spatial patterns that had been extensively trained during Experiment 4. The data indicated that rotation initially reduced CM performance to VM levels. This result is important for the design of C<sup>2</sup> training programs intended to develop automatic processing of spatial pattern information, because C<sup>2</sup> systems can require that operators process spatial patterns in a variety of orientations. Experiment 7 also indicated that some CM versus VM performance differences had been re-established following a period of minimal training with the rotated patterns. The issues of the amount of training required to achieve original performance baselines and the effects of the requirement to process multiple orientations of the same pattern are areas for future research.

Experiment 8 examined spatial pattern information transfer, and investigated the effects of task component recombination on performance within a memory search task. Several conditions that involved the use of previously trained target and distractor patterns were evaluated. The results produced some evidence of both target and distractor transfer within the recombined tasks. A complete reversal condition, in which previous targets served as distractors and previous distractors served as targets, failed to produce negative transfer relative to a control condition involving previously untrained patterns. This may have been related to the requirement to learn new patterns in the control condition and is an issue for future research.

The third series of experiments examined the retention of automatic processing of alphanumeric and spatial information. Experiment 9 investigated the retention of automatic processing

of alphabetic sequences in a memory search paradigm over both three-day and 31-day retention intervals; the results demonstrated no reliable performance losses. Experiment 11 evaluated the retention of automatic processing of alphanumeric information within the rule-based visual/memory search task employed in Experiment 2. The results showed reliable performance losses over a 26-day retention interval. One difference between Experiments 9 and 11 that may bear on the discrepancy in results is the fact that a memory search paradigm was employed in the former experiment, while a more complex visual/memory search task was used in the latter.

Experiment 10, an extension of Experiment 4, examined the retention of automatic processing of static spatial pattern information in a visual/memory search task over a one-month interval. This experiment also demonstrated reliable performance decrements over the interval tested. There were no original part-task versus whole-task training effects on CM retention; this indicated that the part-task training paradigm not only failed to influence the acquisition of automatic processing, but also failed to affect retention as well. In contrast to the results of Experiment 10, an experiment performed during a previous phase (Eggemeier et al., 1991) failed to demonstrate reliable performance losses over a one-month interval with similar spatial pattern information within a memory search paradigm. This discrepancy in retention results may also be attributable to differences between memory and more complex visual/memory search functions. The pattern of results in this series of experiments and in other work conducted under this program (Fisk et al., 1990, 1991) indicates that the type of search paradigm represents an important factor to be considered in the design of training programs intended to maintain operator performance over retention intervals of one month or longer.

A number of the present experiments also addressed the workload associated with performance under CM and VM conditions. Workload reductions associated with CM versus VM task performance represent an important characteristic that can be associated with automatic processing. Experiments 2 and 3 demonstrated subjective workload differences between the two mapping conditions consistent with such a reduction. Experiment 2 indicated that CM conditions led to reliably lower estimates of the workload associated with performance of the rule-based alphanumeric visual/memory search task than did VM conditions. Likewise, Experiment 3 demonstrated that, although increased spatial pattern memory load led to increased workload ratings under VM conditions in a visual/memory search task, comparable increases in memory set size within the CM condition were not associated with reliable increases in workload.

Experiment 12 employed secondary task methodology to evaluate the workload associated with performance of the same spatial pattern search task that had been investigated in Experiment 3. The data of Experiment 12 demonstrated that reductions in performance, associated with performance of a concurrent VM spatial pattern secondary task, were significantly greater with a VM version of the primary visual/memory search task than with a CM version of the same task. These results indicated that the workload associated with the CM version of the primary task was lower than that associated with the VM version of the task. Experiment 12 demonstrated reduced workload in a CM visual/memory search task that required the processing of spatial pattern information representative of one major class of information found in C<sup>2</sup> systems. Extension of the present secondary task work to rule-based tasks which require the processing of complex alphanumeric information of the type found in C<sup>2</sup> systems is an important area for future research.

The present results provide important information for the development of a refined methodology for structuring training programs that will support the acquisition, transfer, and retention of automatic processing in C<sup>2</sup> operator task components. This research, and the recommended extensions of the present work, should contribute to eventual application of an automatic-processing-based approach to high performance skills development in C<sup>2</sup> operators.

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APPENDIX A: EXAMPLE OF A RULE SET OF THE TYPE  
USED IN EXPERIMENT 1

<u>RULE</u>	<u>POSITIVE EXEMPLARS</u>	<u>NEGATIVE EXEMPLARS</u> <sup>1</sup>
DXR 15 - 25	16 18 20 22 24	28 30 32 34 14
DXR 25 - 35	26 28 30 32 34	16 18 20 22 36
FLJ 28 - 38	30 32 34 36 28	18 20 22 24 40
FLJ 18 - 28	18 20 22 24 28	30 32 34 36 16
SKC 76 - 86	76 78 80 82 84	66 68 70 72 88
SKC 66 - 76	66 68 70 72 74	78 80 82 84 64
MTW 63 - 73	64 66 68 70 72	76 78 80 82 62
MTW 73 - 83	74 76 78 80 82	64 66 68 70 84

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<sup>1</sup> In each case, the designated numerical exemplar would be presented with the three-letter acronym that appears under the "Rule" column in the same row as the exemplar.

APPENDIX B: EXAMPLES OF SPATIAL PATTERN MATERIALS  
USED IN EXPERIMENT 3

